5107-1, Vol. 2
Solar Ponds Project

DOE/JPL-1060-50, Vol. 2
Distribution Category UC-62a

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Volume II: Detailed Report

(NASA-CR-168806) REGIONAL APPLICABILITY AND POTENTIAL OF SALT-GRADIENT SOLAR PONDS IN THE UNITED STATES. VOLUME 2: DETAILED REPORT (Jet Propulsion Lab.) 500 p HC A21/MF A01 CSCL 10A G3/44
N82-22665
Unclas
09688

March 15, 1982

Prepared for
U.S. Department of Energy
and
U.S. Department of Defense
Operations Research Department
Through an Agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

(JPL PUBLICATION 82-10, VOLUME II)

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Regional Applicability and Potential of Salt-Gradient Solar Ponds in the United States

Volume II: Detailed Report

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Prepared by the Jet Propulsion Laboratory, California Institute of Technology, for the U.S. Department of Energy and the U.S. Department of Defense, Operations Research Department, Washington, D.C., through an agreement with the National Aeronautics and Space Administration.

The JPL Solar Ponds Project is sponsored by the U.S. Department of Energy and is part of the Solar Thermal Program to develop solar pond technology.

ACKNOWLEDGMENTS

The work reported herein was performed through NASA Task Order RD 152, Amendment 272, and was sponsored by the United States Department of Energy under IAA DE-AT04-80AL13135 and by the Department of Defense, Operations Research Department, Washington D.C. The Benham Group of Oklahoma City, Oklahoma, the Ormat Turbines, Ltd. of Israel, and Utah State University (Drs. J. P. Riley and J. C. Batty) have each performed a subcontract in support of this study. Valuable comments and/or guidance were provided by W. A. Menard, J. C. Becker and J. L. Hesse of JPL, S. Sargent of DOE and K. Meyer of Los Alamos Scientific Laboratory.

ABSTRACT

A comprehensive assessment is made of the regional applicability and potential of salt-gradient solar ponds in the United States. The assessment is focused on the general characteristics of twelve defined geograhic regions, while neglecting site-specific details, and includes: a survey of natural resources essential to solar ponds; an examination of meteorological and hydrogeological conditions affecting pond performance; the identification of potentially favorable pond sites; calculation of regional thermal and electrical energy output from solar ponds; a study of selected pond design cases; an evaluation of five major potential market sectors in terms of technical and energy-consumption characteristics, and solar-pond applicability and potential; a detailed economic analysis considering relevant pond system data and financial factors; and a comparison of solar-pond energy costs with conventional energy costs.

The assessment concludes that, excepting Alaska, ponds are applicable in all regions for at least two market sectors. Compared with conventional energies, solar ponds will generally be able to attain near-term economic viability in several southern, high-insolation regions. Total solar pond energy supply potential in the five market sectors examined is estimated to be 8.94 quads/yr by the year 2000, approximately 7.2% of the projected total national energy demand.

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SECTION 1

INTRODUCTION

1.1 BACKGROUND

The salt-gradient solar pond phenomenon was first reported by von Kalecsinsky (1902) in connection with the Medve Lagoon in Transylvania. It was suggested by von Kalecsinsky, and later by R. Block in 1948, that artificial ponds be established after the natural salt-gradient lakes to harness solar energy for practical utilization. However, development of salt-gradient solar ponds did not take place until the last two decades when the pressure of escalating conventional fuel costs began to be felt. The mid-late 1970s saw several experimental pond programs of modest scale launched in the United States, and some demonstration pond facilities operated in Israel. Much knowledge of solar pond behavior, and experience related to its operation and maintenance have been acquired through these efforts. The demonstration of swimming pool heating by the Miamisburg pond, and particularly of electric power generation by the Ein Bokek pond since late 1979, have called increasing attention to the viability of solar ponds as producers of renewable thermal and electrical energy.

Solar pond development activities have since been accelerated, both in Israel and the United States, as well as in other parts of the world. Notably, Israel has recently started the construction of its first 5-MWe solar pond power plant at the northern end of the Dead Sea. This plant is scheduled to come on line in two years and will be followed by several larger units. Israel hopes to convert the Dead Sea into solar ponds that will have 2000- to 3000-MWe generating capacity by the end of this century. In late 1979, the United States initiated the Salton Sea experiment, with the purpose of constructing its first 5-MWe solar pond power plant in the Imperial Valley of Southern California. The first phase of the activity, feasibility study, has been successfully completed, and the engineering design is now in progress. It is noteworthy that, as a reflection of interest from diverse sectors, the project is co-funded by the U.S. Department of Energy, the California Energy Commission, and the Southern California Edison Company, and is managed by the Jet Propulsion Laboratory. Several other experiments have also been undertaken elsewhere in the United States. They include the TVA pond in Tennessee, the Truscott Brine Lake in Texas, the Gray Mountain pond in Arizona, etc.

As interest in solar ponds grows and development activities expand, it was recognized that a systematic study of solar pond resources, applicability and potential in the United States was in order. The study must be aimed to provide data and analyses needed for a sound planning of near- and long-term development activities and, eventually, commercialization of solar ponds. In August 1980, the Jet Propulsion Laboratory was contracted by the Department of Energy to conduct this study. The findings of the study are presented in this report.

1.2 OBJECTIVES, SCOPE AND DEFINITIONS

The overall goal of the study is to determine the applicability of salt-gradient solar ponds in various market sectors and geographic regions, and to assess the potential of solar ponds to contribute to the total national energy requirement. It is expected that the facts and analyses resulting from the study will provide useful input to the national planning of further development and commercialization of solar ponds.

1.2.1 Objectives

The specific objectives of this study are to:

(1) Evaluate natural resources in the United States that are essential to solar ponds (insolation, land, water and salts). While considering the various physical conditions affecting solar pond performance, identify general areas or specific sites that are suitable for developing solar ponds.

(2) Examine the regional characteristics of solar pond performance, and conduct representative and comparative case studies to determine important design parameters of solar ponds and the associated energy distribution systems. This will provide useful reference cases for future solar pond design and development, as well as supply concrete data for the economic assessment which is an integral part of this study.

(3) Survey potential market sectors in which solar ponds can be employed to supply thermal or electrical energy. Determine the amount and pattern of energy consumption in these market sectors, and assess how and to what extent solar ponds can contribute to each sector's energy requirement.

(4) Perform economic analysis to determine costs of delivered energy from solar ponds, taking into account all relevant financial factors. Also determine conventional energy costs and compare the costs of energy from solar ponds with those from conventional fuels, considering regional variability.

(5) Determine solar pond applicability in the various market sectors on a regional basis. Develop estimates for energy supply potential of solar ponds by regions and by market sectors.

(6) Document results of the study and provide the sponsors and potential users with realistic assessments of solar pond applicability and potential, and with recommendations concerning future development and commercialization of solar ponds.

1.2.2 Scope

The study encompasses the entire United States (which is divided into 12 geographic regions, as described in Section 3.1). It addresses five major potential market sectors, and a large number of technical and economic factors. Those factors which generally vary with time and location, e.g., environmental, social, political, and institutional factors are not considered in any detail. The five major potential market sectors are the residential, commercial and institutional buildings sector, the industrial process heat sector, the agricultural process heat sector, the electric power sector and the desalination sector. The technical factors considered include the four essential natural resources (i.e., insolation, land, water and salts); climatic, geological and hydrological conditions; design parameters (i.e., the solar pond, power conversion, and energy distribution subsystems); construction aspects; performance; and operation and maintenance aspects. The economic factors considered include solar pond life-cycle costs, and conventional energy costs. In calculating solar pond life-cycle costs, several important financial elements are taken into account: application-specific discount rates, accelerated depreciation method, tax rates, inflation rate, investment credits, escalation rates for capital, O&M and fuel costs, etc.

The key factors mentioned above affect the applicability and potential of solar ponds in different ways depending on the region and market sector considered. For example, insolation level may render electric power generation viable only in certain regions. Climatic conditions may be such that, although building space heating is required in most regions, pond output may not be adequate to effect economic viability in all. Also, within a given region, solar ponds may be well suited and widely employed for a particular market sector, but not the others. The interrelations among the key factors, the geographic regions and the market sectors are complex. Figure 1-1 summarizes and indicates the interrelationship among the various elements addressed in this study.

1.2.3 Definitions

The following terminologies are used in this report repeatedly and have specific meanings.

Salt: A chemical substance which can be dissolved in water to produce a density gradient. It is not limited to sodium chloride or magnesium chloride although these are common examples. "Salts" are employed to indicate a combination of such substances.

Brine: The solution obtained by dissolving salts in water. The term applies to both artificial and natural solutions such as ocean water.

Salt-gradient solar pond: A body of water which is hydrodynamically stabilized by a density gradient constructed with dissolved salt(s) and which is utilized to collect and store solar energy.

Solar Pond: Or sometimes simply "pond." Used synonymously with "salt-gradient solar pond," unless otherwise noted. Other types of solar ponds, e.g., shallow solar pond, saturated pond, gel pond, etc., are not discussed in this report.

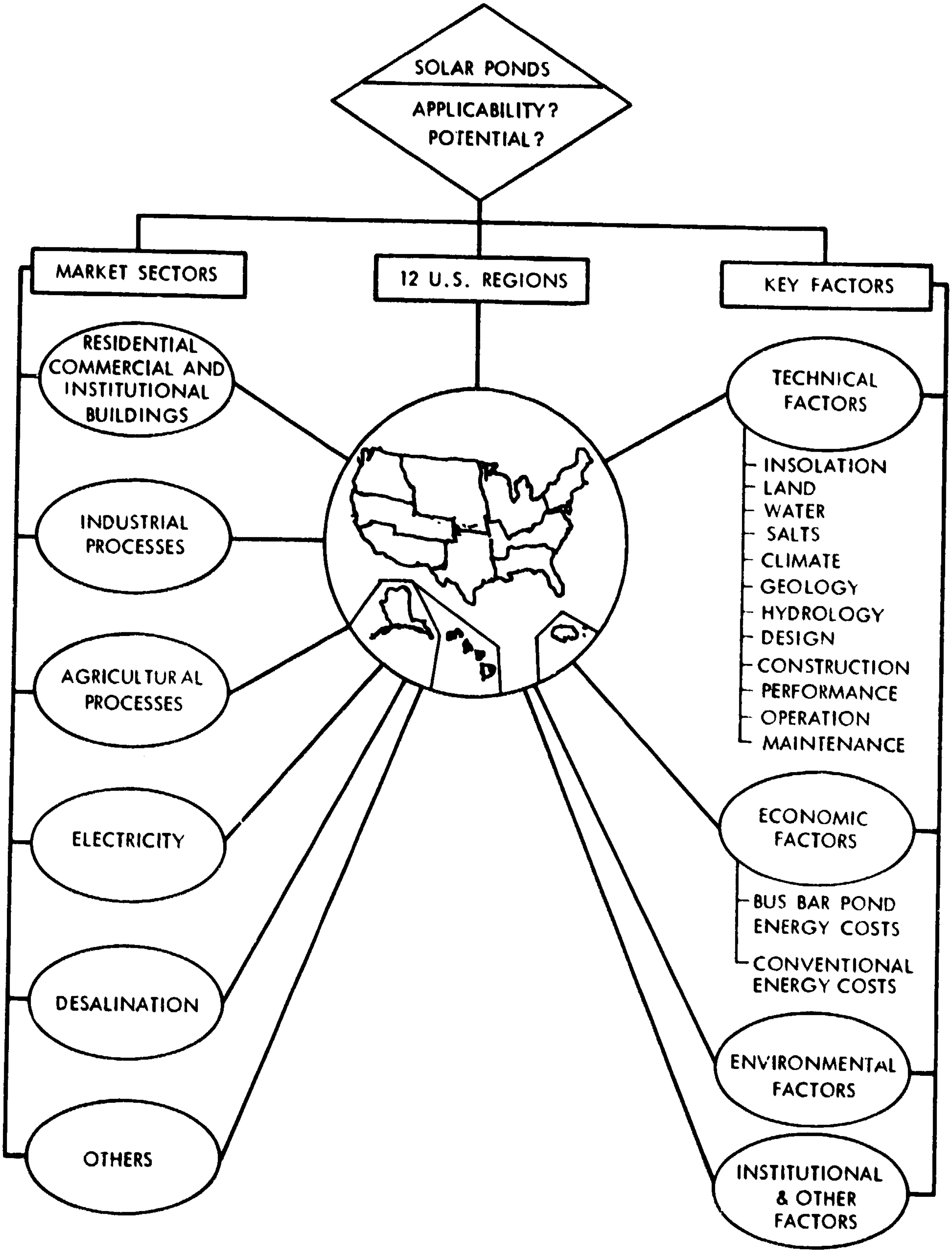

Figure 1-1. Scope of the Regional Solar Pond Applicability and Potential Study

Thermal and electrical energy: Thermal energy refers to energy delivered from a pond in the form of heat, normally in the temperature range of 86 to 212°F. Electrical energy is generated from thermal energy by a power conversion subsystem such as an organic Rankine cycle unit.

Solar Pond System: The total solar pond system is composed of the pond subsystem (the pond, brine, liner, wave-suppressing network, brine circulation and surface flushing devices, gradient monitoring and control instruments, evaporation pond, brine storage pond, water treatment equipment, and related accessories); the energy distribution subsystem (the heat exchangers, piping, transmission lines, and related accessories); and/or the power conversion subsystem (evaporators, condensers, turbines, generators, preheaters, and related accessories). For thermal applications, the solar pond system consists only of the pond and energy distribution subsystems; whereas for electricity production, the solar pond system includes also the power conversion subsystem. In the latter case, the system is often referred to as a solar pond power plant.

End User: An end user receives thermal or electrical energy from a solar pond system. An end user can be a building, a factory, a farm, a utility power grid, etc.

1.3 ASSUMPTIONS, METHODOLOGY AND LIMITATION

Owing to the broad scope of the study, site-specific considerations are not possible. Almost all computations, discussions and assessments are conducted on the regional level. A regional-level treatment of the subject matters is justified, however, as explained in Section 3.1. Efforts have been made to collect up-to-date information on which many discussions and evaluations are based. However, up-to-date information is not always available, in which case older information sources are relied upon as necessary.

1.3.1 Assumptions

Numerous assumptions are made in the study. Where they occur, they are stated as explicitly as possible, and justifications/implications, if any, are discussed. It is important that readers of this report are aware of, and view the results in light of, these assumptions. Although detailed assumptions are described in the text of the report in the appropriate places, the important ones are summarized below.

(1) The study is conducted on the regional level. Site-specific considerations are beyond the scope of this study.

(2) Assessments of solar pond applicability and potential are made for the various regions and market sectors with attention focused on the technical and economic factors. Environmental, social, political, institutional, and other factors, being site specific in most cases and often time dependent as well, are not addressed.

(3) Projections and extrapolations, wherever appropriate, are made on the basis of "best" information obtainable at the time of the study. It is possible that more current or comprehensive data sources exist but are not readily accessible or not known to the investigators, and consequently not utilized in the study. In such cases, the related results may have to be modified accordingly.

(4) In the regional assessments and comparisons, some representative cases are selected for study which are associated with specific cities or locations. Solar pond performance and economic characteristic of these selected cities or locations are assumed to be representative of the entire region to which they belong. Variation of key parameters (such as land availability and cost, solar pond energy output, and conventional energy cost) within a given region is recognized, and must be considered in any future site-specific study.

(5) Estimating solar pond market potential in the residential, commercial and institutional building sector is confined to space heating/cooling and domestic water heating applications. In the industrial process heat sector, only the manufacturing processes are considered. In the agricultural process heat sector, the estimate includes applications such as crop drying, irrigation, livestock care, and farm house and greenhouse heating. In the desalination sector, all the major processes (i.e., distillation, reverse osmosis and electrodialysis) are considered. In the electric power sector, attention is focused on the potentially limiting factors such as water and salts.

1.3.2 Methodology

After detailed tasks were specified in the work statement, the first step was to collect pertinent information and data and analyze them. As part of this step, insolation mapping was found necessary, as the existing maps were outdated and known to be based on sketchy or inadequate insolation measurements. Best available data and analysis techniques were utilized to obtain a new set of isoinsolation contours on which the region definition is based. Other pertinent data collected include existing information on salts/brine, water, ambient temperature, evaporation, precipitation, topography, soils, ground water, wind, seismic and hurricane activities, relative humidity, etc.

Analysis of these data preceded the definition of geographic regions. As explained in Section 3.1, several practical criteria were considered to arrive at the 12 defined regions.

Concurrently, a JPL solar pond performance model was under development for the Salton Sea project. Several modifications were implemented into the computer code for computing regional energy outputs. Also, the Energy

Systems Economic Analysis (ESEA) model, which was developed over the years at JPL for the various solar thermal power projects, was adapted for solar pond economic assessments.

A salts resources survey was then conducted, with the specific purpose of identifying locations where salts or brine is readily available or can be easily mined. The availability of salts or brine is a major determining factor for constructing solar ponds, especially the large-scale electricity producing facilities. Where practicable, a survey was made of the availability of clay and fresh water, as these are also requisite source materials. The identification of especially attractive sites for solar pond implementation was an important product of this exercise, and a large amount of information results from a literature survey and communications with state geologists.

A nation-wide survey of land availability and cost was also conducted. Land issues are more involved, as has been found out by previous investigation in connection with other solar technologies, so attention was confined to the residential, commercial and institutional buildings market sector. The rationale is that in this market sector, land is more likely a limiting factor than in others. This is also true, but to a lesser extent, for the industrial sector. Land is generally regarded as being amply available in the agricultural, electrical and desalination sectors, as solar ponds will be located within the large acreage of farm lands, or areas remote from population centers. This survey was conducted by a subcontractor, the Benham Group of Oklahoma City, using statistical and survey techniques appropriate to the task.

A number of design cases were specified for detailed studies. Ten cases are concerned with space and domestic water heating of apartment complexes in the various regions, and the other cases deal with agricultural, industrial and electrical applications. The purpose of the case studies is to provide a basis for regional comparisons, a set of reference cases for future site-specific designs, and to develop cost estimates for use in the economic analysis. Ormat Turbines, Ltd., of Israel was selected to be the subcontractor to perform this task. Ormat used its in-house pond performance model and energy conversion system design techniques to carry out the pond subsystem designs. A study of the energy distribution subsystems was also performed at JPL for several selected applications. Here representative designs were given for integrating the solar ponds and the end uses into complete systems.

The JPL solar pond performance model was used to calculate pond energy output in each of the 12 defined regions. A city was chosen to represent each region in the calculation, with the computed energy output to be interpreted as average yield. Regional energy outputs are important factors in determining the cost of energy delivered from solar ponds.

A significant amount of effort was devoted to the survey of potential market sectors. As the solar pond technology moves toward the commercialization stage, an understanding of potential markets will be desirable. Surveys of individual markets were conducted to determine market-specific characteristics, ways in which solar ponds can be applied in each sector, each sector's current energy requirements, and the extent to which solar ponds can

contribute to those energy requirements. Each market survey was conducted separately, and the needed information was derived from the published literature or private communications.

Economic analysis is an important element of the comparative regional study. The adapted ESEA model was used as the analysis tool. Input to the model included engineering-related items, such as system lifetime, costs and some details of construction, operation and maintenance, and regional energy outputs. It also included a variety of financial factors, such as discount rates, escalation rates, accelerated depreciation, income tax rate, investment tax credit, insurance and other tax rates. Furthermore, costs of conventional energy (e.g., energies derived from oil, natural gas, coal, etc.) were surveyed. By comparing the costs of energy obtained from solar ponds with those from conventional fuels, the economic viability of solar ponds for various applications in various regions were established. To assess pond applicability and potential, it was necessary to evaluate the requisite natural resources and technical factors in conjunction with a market survey and an economic analysis. These three tasks provided data, analyses, observations, evaluations, and conclusions upon which solar pond regional applicability was assessed in terms of technical and economic feasibility. Potential was expressed in terms of estimated acreage of constructed ponds, and estimated energy supply in quads that solar ponds can contribute.

Conclusions were then drawn and recommendations made with federal and state level decision makers and private end users in mind. Among other things, regions and markets of high potential are identified, highly attractive sites are pointed out, further studies needed are indicated, and approaches or strategies toward further development and/or commercialization are suggested.

The methodology and logical sequence of task execution as described above are summarized in Figure 1-2.

1.3.3 Limitation

The validity of the content of this report rests on the general assumptions stipulated earlier in this section and those stated later where appropriate. The accuracy of the quantitative computations, assessments, projections, or statements depends upon that of the data or information used. The conclusions regarding the applicability and potential of solar ponds are drawn from regional considerations of technical and economic factors. Environmental, social, political, institutional and other site-specific factors were not considered. These latter considerations must be included in the determination of the viability of any individual project.

1.4 PREVIOUS SOLAR POND APPLICABILITY AND POTENTIAL EVALUATIONS

Numerous publications in the solar pond literature have, in varying degree, addressed the question of applicability and/or potential of solar ponds in the United States. Most were cursory treatments and many dealt only with specific applications. Few presented a systematic and comprehensive assessment, and none covered the entire United States. The reason is simple. The need did not previously exist. The emerging solar pond technology has only

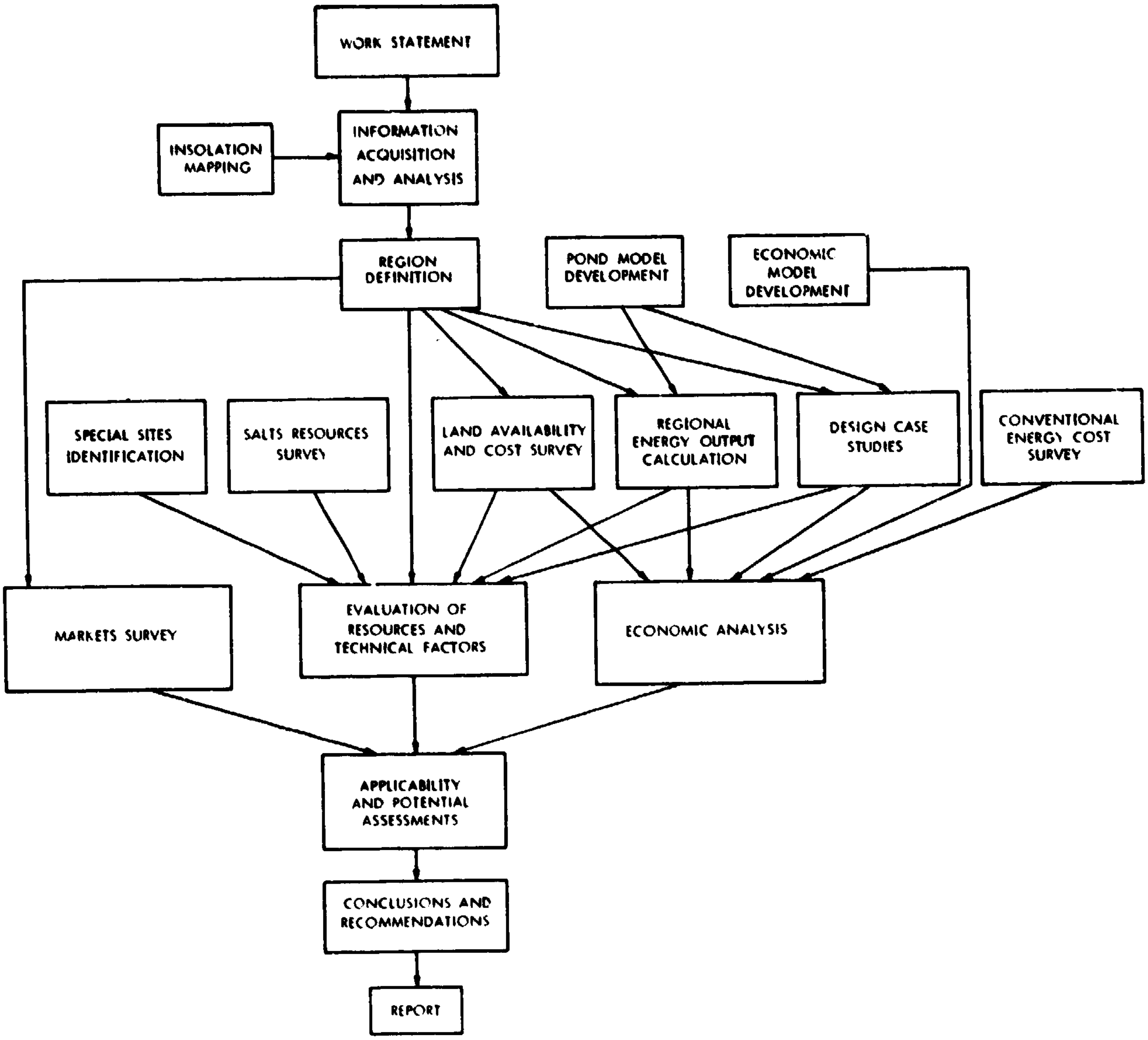

Figure 1-2. Task Flow Diagram for the Regional Solar Pond Applicability and Potential Study

recently has advanced to where larger scale development and commercialization could be considered.

During 1974-1975, just when the first solar pond projects were getting under way in the United States, several studies were sponsored by AEC and its successor ERDA to evaluate the status and prospects of solar ponds. Three reports were published in 1975: two by Pacific Northwest Laboratory (Styris, Zaworski and Harling, 1975; Drumheller et al, 1975) and one by Bechtel Corporation (1975). The three reports agreed in noting that the technical feasibility of salt-gradient solar ponds were not yet established, and that technical unknowns and uncertainties were numerous and must be resolved by conducting Research and Development (R&D) work. Areas of technical concerns included pond lifetime, heat extraction, energy conversion, brine management, gradient stability, pond operation and maintenance, etc.

However, these reports disagreed on their conclusions regarding the prospects of solar ponds. The Styris, Zaworski and Harling report recognized that solar ponds were the least costly of all solar collection and storage systems. It concluded that the costs of electric energy from solar ponds were close to those of fossil fuel generated power (for an area with average insolation of approximately 240 W/m^2), and that solar ponds were economically competitive with oil and natural gas in process heat applications, such as crop drying, paper industry processing, etc. (for Richland, Washington). In contrast, the Drumheller report concluded that electric power production from solar ponds was not cost competitive with other conventional systems, but that thermal applications of solar ponds can be. However, the Bechtel report, addressing exclusively electric power generation with solar ponds in the southwestern United States, concluded that electric power generation by solar ponds was at least an order of magnitude more expensive than by conventional means, and that this was true not only for the United States but for the developing countries as well. Another article (Rabl and Nielsen, 1975) discussed using solar ponds for space heating in several different locations and climates and concluded that this was technically and economically feasible even near the arctic circle, if reflectors were utilized to enhance solar collection.

These assessments used varying technical assumptions and cost data, some of which were later found to be valid, but others not. They represent views of the pre-development days. Since 1975, several solar ponds have been constructed and operated in the United States and Israel and many of the technical unknowns and uncertainties concerning solar ponds that existed in 1975 have been resolved (Nielson, 1980; Lin, 1982; and Tabor, 1981). The demonstration of electricity production with the Yavne and Ein Bokek ponds in Israel has been widely publicized as evidences that solar ponds do work. The outlook of solar ponds has improved substantially since 1975 due to the knowledge and experience gained during the past years. This is reflected in many recent publications.

For example, Ochs (1980) discussed solar ponds as industrial process heat sources and estimated that they can contribute up to 2.4 quads if both direct usage and preheating are considered. Lin, Sha and Soo (1980) analyzed the technical and economical feasibility of solar ponds in largescale agricultural applications. They determined that a 1-acre pond can supply adequate heat to meet the grain drying and space heating requirements of a

500-acre Illinois farm, and that the cost of heat from solar ponds was only slightly higher than that from LP gas which is commonly used on farms. Bronicki (1980) reported the performance of the 150-kWe pilot solar pond power plant at Ein Bokek and projected the energy yield, efficiencies and cost of larger plants. He estimated the cost of electricity from solar ponds to be from 10 to 15¢/kWh for peak loading systems and from 4 to 8¢/kWh for base and intermediate loading configurations (in 1980 dollars). Wittenberg and Harris (1980) reported the use of the Miamisburg pond in heating an outdoor swimming pool and estimated heat cost at $7.2/MBtu.[2]

Recently, Edesess (1980a) made an estimate of the potential of solar ponds for displacing conventional energy sources in the United States, based on current national energy consumption, and assumptions on consumption growth, market penetration, market characteristics, etc. He projected that, by the year 2000, solar ponds can contribute 2.3 quads/yr to the residential and commercial space and water heating market, 0.6 quad/yr to the agricultural and industrial low temperature process heat market, and 2 quads/yr to the electric power market. This represents a total of 4.9 quads/yr, and about 5% of the entire national consumption in the year 2000. Edesess also conducted a simplified economic analysis (1980b) and computed the cost of electricity from solar ponds to be from 6.5 to 62¢/kWh, and the cost of heat from $0.8 to 23.1/MBtu, depending on pond location, capital cost, end-use temperature, etc. Compared with conventional energy sources, he concluded that solar ponds are (or are nearly) competitive for thermal applications, and can be competitive for electric power production if low pond costs can be obtained at favorable sites.

Tabor (1981) discussed in his recent review article the applications of solar ponds to building heating and cooling, electric power generation, desalination, and salt production, in general terms. He also estimated busbar power costs in the range of 5.3 to 13.5¢/kWh under favorable insolation conditions, and indicated a very promising outlook for solar ponds. Another recent solar pond potential evaluation worthy of note concerns assessing solar pond potential in the State of Utah, including the Great Salt Lake and other potential sites (Riley and Batty, 1981). Water supply is identified to be a future limiting factor in Utah, and the total energy supply potential for Utah was estimated to be 3.24 quads/yr.

1.5 STATUS OF SALT-GRADIENT SOLAR POND TECHNOLOGY

A brief description of a salt-gradient solar pond is given in Appendix A. Preceded by the Israeli studies in the early 1960s, research and development efforts undertaken during the last seven or eight years, principally in the United States and Israel, have advanced the solar pond technology to the point where it can be referred to as a proven technology. Although questions remain to be answered, much has been learned. Nielsen (1980), Lin (1982), and Tabor (1981) review the state of the technology in detail, and cite

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[2] MBtu = one million Btus.

a large number of publications which can be consulted for further information. Only a brief overview of the pond technology is provided in what follows.

One or two dozen solar ponds, all under two acres in surface area, have been constructed and operated around the world (mostly in the United States and Israel). Construction of small ponds (excavation, diking, lining, filling, installing piping and instrumentation, etc.) has proven to be straightforward. Several larger ponds are either under construction or design, including Israel's 5-MWe plant and the Salton Sea 5-MWe experimental pond. Inlake diking and high salinity brine production from low-salinity water may be improved by innovative approaches, but can be accomplished with standard techniques.

Pond storage temperature varies from a low of about 30°C in winter (Ohio) to a high of 109°C in summer (New Mexico). Boiling can be achieved in high-insolation locations and can be avoided by scheduled heat extraction. Heat extraction both by in-pond and out-of-pond heat exchangers have been successfully performed, the latter means being preferred from experience.

A variety of thermal applications have been successfully demonstrated, including pool heating, grain drying, process water heating, space and greenhouse heating, etc. The Yavne and Ein Bokek ponds have established the feasibility of peaking and baseload electric power generation. Larger scale applications remain to be demonstrated, but their success is anticipated. Thermal efficiency on the order of 10 to 20%, and thermal-to-electrical conversion efficiency of 8 to 9%, have been established.

The salt-gradient zone has been found to be generally stable. No dramatic failure of the gradient has occured. Convective sublayers of a few centimeters thick have been observed within the gradient zone and simple methods have been established to rapidly correct them. Boiling was found to cause gradient instability and large amount of heat losses, but it did not destroy the gradient completely. Divers performing maintenance/repair did not disturb the gradient zone in any noticeable way. Knowledge is being gained of the mechanisms and physical factors that control gradient boundary migration and its thermal and hydrodynamic behavior, although a complete understanding has not been achieved.

Salt diffusion from the storage to the surface zone can be countered by reinjecting salts or heavy brine into the storage zone and flushing the surface with fresh or low-salinity water. This has become a standard practice for every operating pond, and the effort involved is minimal.

High winds have not produced any damage to the ponds. Wave-suppressing networks installed on pond surfaces have been effective in preserving the pond's integrity even during gusts in excess of 120 km/hr. No record exists of any pond damage due to rain or hail storms. Two or three months' snow and ice coverage on the pond surface do not drastically degrade a pond's performance. Ponds located in the low-insolation northern states are capable of sustaining a storage temperature of about 30°C during the winter months. Fallen leaves, dust and debris can be easily removed from the pond by surface flushing or swimming pool type cleaning techniques. Algae growth can be prevented by applying copper sulphate and other chemical substances.

Reaction between hot brine and pond bottom mud in an unlined pond can potentially lead to gas bubbling or rising sediment, but laboratory experiments show no evidence indicating that this is a cause for concern. Turbidity and coloration can reduce solar transmittance into the storage zone, but proper water treatment including settling, filtering and carbon treatment has been found to be effective in removing the suspended particulates and organic matters that cause these problems. Corrosion has damaged the heat exchangers of the Miamisburg pond, but has not done any damage to other pond installations. Liner breakage has occurred to two ponds; causes for breakage were determined and repairs performed. Salt leakage accompanying liner breakage was not found to severely contaminate the environment. Evaporation from open pond surfaces resulting in water losses can pose some constraints on pond applications, especially in arid regions where water is in short supply. Evaporation suppressants which can be applied to pond surfaces are being investigated. Earthquakes and tornados have not been experienced by any existing ponds. They may conceivably damage ponds, but special design considerations and repairs can be excercised as they are with other types of structures or power plants. No ponds have been a visual, safety or any other type of environmental hazard.

In short, what has been learned and experienced of solar ponds has been positive. The capability of ponds to collect and store solar energy has been repeatedly confirmed, even in areas where insolation is relatively low. They have been proven to be viable producers of usable thermal and electrical energy. This does not mean, however, that all the problems have been solved. Research and development are still needed in a number of important areas. These include surface zone phenomena, gradient stability, heat extraction rate and methods, water treatment techniques, mud-brine reaction, evaporation suppression, dydrodynamic effects of scaling up pond sizes, system optimization, brine concentration techniques, dike construction schemes, and improved operation and maintenance procedures. These investigations will further our understanding of solar ponds, improve their design and construction, enhance their performance, and reduce the costs of thermal and electrical energies that are derived from them.

SECTION 2

NATURAL RESOURCES AND PHYSICAL CONDITIONS PERTINENT TO SOLAR PONDS

2.1 NATURAL RESOURCES

2.1.1 Insolation

Solar radiation is by far the most important natural resource that solar ponds utilize. It directly affects the energy output of a pond, and is a key parameter in determining the applicability of solar ponds to a given location.

Sufficient insolation is available in most parts of the United States to support solar pond operations, and the southwestern United States is among the world's highest insolation regions. Although higher in latitude than many countries near the equator (e.g., India, South America and Central Africa), the southwestern states have peak insolation levels that rival those countries.

The variation of insolation levels within the United States is significant. Hence, the thermal and electrical energy output from solar ponds, and the economics of solar ponds, will also vary significantly from region to region, as will be seen in Sections 3 and 6. Therefore it is important to have as accurate an insolation data base as possible.

This section presents solar insolation data pertinent to a regional evaluation of solar pond energy generation potential in the continental United States. The data are presented in tabular form as well as in contour maps displaying both a continuous gray scale representation of insolation values and isoinsolation contours at regular intervals.

The data are preceded by a discussion of the nature of the raw data base available for the analysis, including its limitations, and a brief presentation of some fundamental considerations necessary for an understanding of solar insolation data. (For a more detailed discussion describing measurement techniques, data reduction, and methods of contour generation, see Appendix B.)

2.1.1.1 Solar Insolation Data. The term solar insolation refers to the power per unit area integrated over a given solid angle about the normal to the surface, and over all wavelengths within the approximate range of 0.3 to 5.0 μm. The exact quantity specified depends on the orientation of the surface normal as well as the field angle involved, and two different insolation components are generally considered.

Insolation Term	Approximate Field Angle	Orientation of Surface Normal
I_{DN}	10°	Toward Sun
I_{TH}	180°	Vertical

where I_{DN} = direct normal insolation, and I_{TH} = total horizontal, or total hemispheric insolation.

In addition to these, reference is also made to the Diffuse Horizontal Insolation, I_{dH}, defined by the relation:

$$I_{dH} = I_{TH} - I_{DN} \cos Z,$$

where Z = zenith angle of sun.

The relevance of these components depends on the specific application under consideration. Thus, analysis of solar tracking, point focusing paraboloidal mirrors requires a knowledge of I_{DN} (Latta, Fujita, and Richter, 1980), while tilted flat plate collectors must use all three components combined with knowledge of the collector orientation (Kusuda and Ishii, 1977). For solar pond applications, the I_{TH} term is important.

Although many insolation measurements have been made at a large number of sites in the United States over a period of many years, the quality of the data and its availability are such that its use and interpretation are far from straightforward (Durrenberger and Brazel, 1976).

The most extensive data giving broad national coverage is that which has been gathered by the National Weather Service and archived by the National Climatic Center. These have been gathered by the stations of the Climatological Solar Radiation and Meteorological Data Network (SOLMET) over a period extending from 1952-1976, and form the basis for the data presented in this report.

Although the SOLMET data is the most extensive available, it suffers from a number of difficulties. These include:

(1) Limited number of sites. Although the SOLMET network presently consists of 39 sites, many of these have been only recently been established, and useful long-term records exist for only 25 stations.

(2) Errors. It has been acknowledged for about a decade that serious errors (of the order of 20% in some instances) have occurred over the years during which insolation data have been collected. These have resulted from a combination of instrument drift and calibration problems resulting from inadequate maintenance of the instruments as well as inherent instrument design problems.

(3) Missing data. This problem has continued to plague the SOLMET system. Even recent data are affected (Appendix B).

To a certain extent these limitations have been overcome by extrapolating measured values of insolation at the 25 sites to a much larger number of meteorological stations (197), and applying corrections to the original SOLMET data in an effort to reduce errors and fill in missing data. Although this effort has undoubtedly resulted in a much improved data base for solar insolation, the resultant "rehabilitated" data remain open to criticism

on the basis of accuracy (Rapp, 1979a). Most serious among such criticism is that there may be a systematic error resulting in an underestimate of insolation values in the northwestern part of the country (Rapp, 1979b).

A further complication arises through attempts to characterize a non-stationary phenomenon by averages obtained over a given period of time. Long-term historical data show, for example, that variations in upper atmospheric turbidity caused by volcanic activity typically result in atmospheric transmission variations of 5 to 10%, and in some cases as much as 30% (Watt Engineering Ltd., 1978).

Consequently, estimates of solar insolation, and in particular regional comparisons made for the purpose of assessing energy production potential and cost, must be viewed as estimates subject to error. It is probable, but by no means certain, that regions in the high latitudes have higher average insolation values than are represented by the best data available, which form the basis for the estimates presented in this report.

2.1.1.2 Total Horizontal Insolation Values for the Conterminous United States

The insolation map presented in Figure 2-1 was generated from data taken from the publication "Input Data for Solar Systems," prepared by the Department of Commerce for the Department of Energy (Cinquemani, Owenby, and Baldwin, 1979). Values are expressed in units of kWh/m^2-day. The gray scale calibration corresponds to a value of 8 for white and 0 for black. They are based on a total of 222 stations of which 25 contain rehabilitated hourly measurements, while the remaining 197 contain derived values based upon the rehabilitated data from the 25 stations plus meteorological data gathered at each station. All 222 sites used in the study are shown on the map. The data are averaged over a period of approximately 25 years from the early 1950s to the mid 1970s.

For a listing of the weather stations together with their latitude, longitude, elevation, and monthly as well as annual average total horizontal insolation values expressed in units of Langley/day, see Appendix B, Section 2.

The procedure used to generate the contour maps involves the generation of a discontinuous I_{TH} surface from the values listed in Appendix B, Section 2, and the subsequent smoothing of that surface by a 2-dimensional spatial filtering scheme. Different amounts of smoothing results in different sets of contours. (Details of the map producing technique are described in Appendix B, Section 1.)

2.1.2 Land

Solar ponds are a land-intensive technology. Because of the diffuse nature of solar energy, large land areas are required to locate ponds for its collection and storage. Requirements on land vary with application and can range from less than an acre to thousands of acres. Land availability and land value change from location to location, and affect solar pond economics on a site-specific basis.

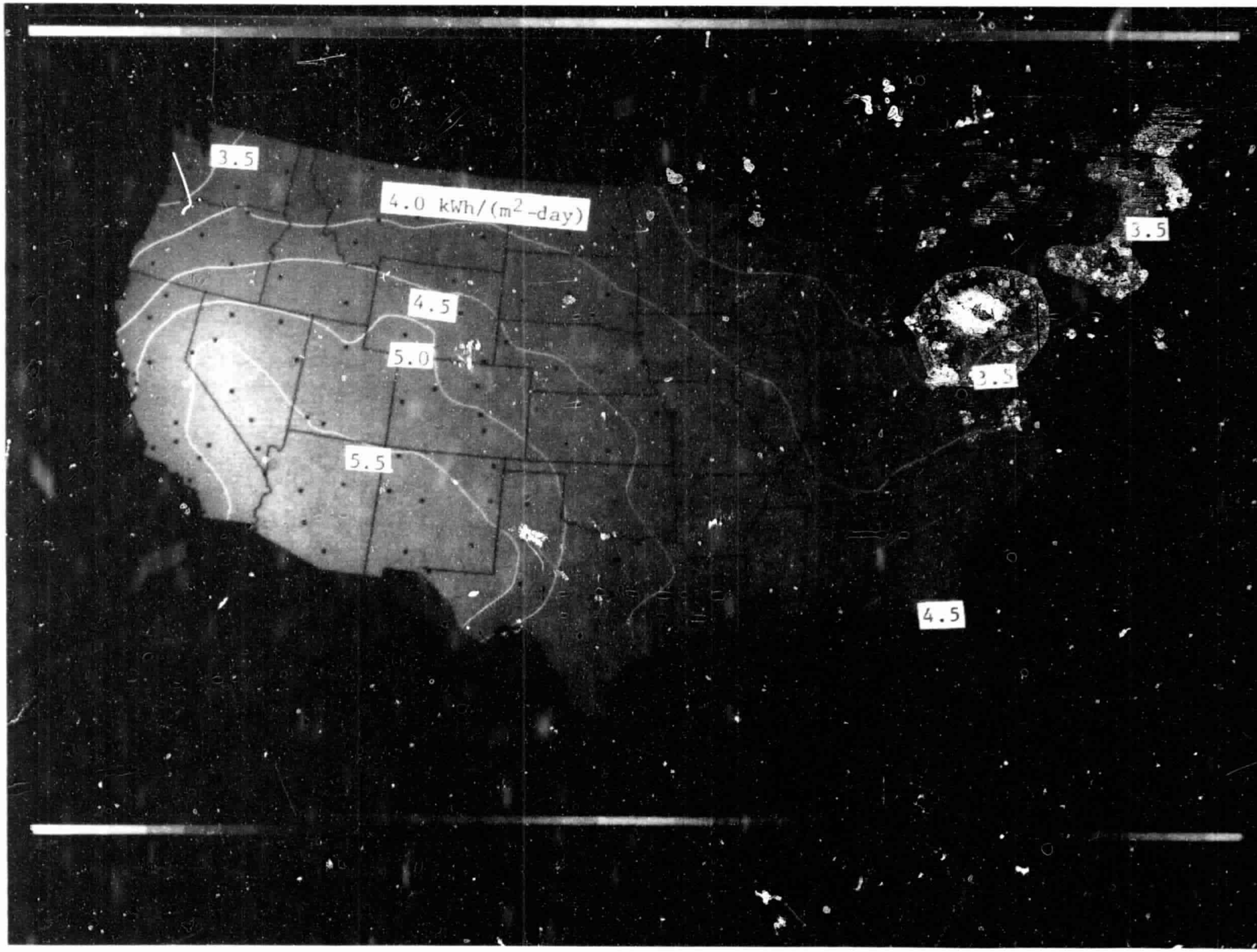

Figure 2-1. Annual Averaged Total Horizontal Insolation Contour Map for the Conterminous United States

Depending on the solar pond application, land may or may not be a limiting factor as compared with other natural resources required for solar ponds (i.e., insolation, salts and water). For example, in the electric power market sector, huge ponds are normally expected on sites that are remote from population centers, where salts or brine are locally available, and where insolation and water are abundant. In the agricultural sector, sufficient land should normally be available for locating a 2-acre pond on a 500-acre farm. In the desalination market sector, many future desalination plants can be expected to be built on low-cost lands. Therefore, land is not considered to be a limiting factor in these market sectors.

The industrial market sector, however, is more susceptible to land restriction, as many plants located in metropolitan areas simply cannot afford the land to on which build solar ponds. The residential, commercial and institutional buildings sector is by far the most restricted by land availability and land cost. Especially in developed residential areas, low-cost vacant land that is sufficiently close to existing buildings is generally scarce. Therefore, retrofitting of solar ponds in developed residential areas is not expected to be a sizable market. The possibility does exist, however, for solar ponds to be incorporated into the planning considerations of the undeveloped buildings sector.

Information on land availability and land value is extremely difficult to obtain. Development pattern varies widely from city to city, and even within a city. Also, information is often not well documented, or not documented at all. To attempt a regional characterization of the availability and values of land is in itself a major undertaking. It entails a laborious gathering of site- or city-specific data, and making various assumptions including stipulating the rules of generalization.

As part of this study, JPL contracted with the Benham Group (formerly Benham Blair and Affiliates, Inc.) of Oklahoma City, Oklahoma, to conduct a regional survey on land availability and land values throughout the United States. The survey focused on the residential, commercial, and institutional buildings sector, because land appears more limiting to this market sector than to others, as far as developing solar ponds is concerned. The purpose of the survey was to establish a data base, and to estimate and analyze, on a regional basis, the amount and value of land that is physically available for potential solar pond development.

The Benham Group examined over 2,200 cities throughout the United States and Puerto Rico whose populations are greater than 10,000. By analyzing and categorizing population densities, and by a random selection process coupled with consideration of physiography and the availability of U.S. Geological Survey maps, the Benham Group selected 30 cities for case studies. For each study-case city, they conducted telephone interviews and sent out questionnaires to collect data on land use, land availability, land value, and zoning regulations from city/community officials, realtors, or appraisers. Data collected were then analyzed to determine developed and undeveloped acres in the residential, commercial and institutional categories, pond-suitable land in each category, maximum building units permitted under existing zoning codes, single family vs. multifamily building units and acres, and land values by a low-medium-high range classification. Following completion of the 30 study cases, regional projections were made. To do this, the Benham Group first

determined the total area for each density category within a region. By assuming the same development pattern for all cities in the same density category, the case study city results were used to generate the regional totals of developed and undeveloped areas, and total acres of pond-suitable land in the developed and undeveloped categories. The split into residential, commercial and institutional categories, as well as into single family and multifamily residential categories, was also fashioned after the study case cities in the region.

The reader is referred to the Benham Group final report (1981) for more details on their survey and analysis methodology, and the 30-city case study results. Their regional projections on land availability in the residential, commercial and institutional buildings sector are included here as Tables 2-1 through 2-9. Their regional comparison on land availability and land use is presented here as Tables 2-10 and 2-11, and Figure 2-2. Their regional comparison on land values is given here in Table 2-12 and Figure 2-3. For ease of reference, graphical representations of their study case results on land availability and land values are also included in Appendix C and D respectively. The legend is given on the first page in each of these Appendixes.

Table 2-10 compares, by region, the total amount of city acreage for cities with a population greater than 10,000, the total pond-suitable land (PSL), the total undeveloped PSL, and the total undeveloped residential PSL as divided into single family and multifamily segments. Alaska, Hawaii, and Puerto Rico have been excluded from regional comparisons due to insufficient data. The three regions exhibiting the most total city acreage are the Atlantic Northeast, the Great Lakes, and the Red River regions. The smallest region is the Black Hills region, whose 0.34 million acres represent only about 16% of the largest region.

Total PSL includes the combined estimate for developed and undeveloped lands. Again, the Atlantic Northeast maintains the number one ranking but is followed closely by the Tennessee Valley and Red River regions. The Black Hills region is again the smallest, consisting of only 5 to 6% of the total PSL acreage present in the Atlantic Northeast.

Undeveloped PSL is the total amount of land that could potentially and realistically be set aside for solar pond application in the undeveloped portions of urban settings within a region. The Red River region heads the list with the most undeveloped PSL, with the Atlantic Northeast and Tennessee Valley regions second and third, respectively. As before, the Black Hills region is at the bottom of the list with the lowest total of undeveloped PSL.

Residential land is conveniently divided into single family and multifamily segments. A national average has been used to determine the single/multifamily split: 87% of the land use is single family; 13% is multifamily. In the undeveloped single family/multifamily PSL category the Atlantic Northeast again is the leader with the most single family/multifamily land potentially available. The Red River region ranks second in the single family market and third in the multifamily area, whereas the Tennessee Valley region ranks third and second, respectively, in those two categories. The smallest amount of single family/multifamily PSL is in the Salt Lake and Black Hills regions. These two regions rank either 8 or 9 in this analysis (Table 2-10).

Table 2-1. Land-Availability Projections: Atlantic Northeast Region

Development Category	(1) City Density Category	(2) Total Acres for Cities >10,000	Developed Land (3) Developed Acres	Developed Land (4) Percentage of Pond-Suitable Land[a]	Developed Land (5) Total Acres of Pond-Suitable Land[b]	Undeveloped Land (6) Undeveloped Acres	Undeveloped Land (7) Percentage of Pond-Suitable Land[a]	Undeveloped Land (8) Total Acres of Pond-Suitable Land[c]
Residential[d]	Low		240,374	32-35	76,920-84,131	961,498	32-35	307,679-336,524
	Medium		1,060,029	32-35	339,209-371,010	305,311	32-35	97,700-106,859
	High		218,596	32-35	69,951-76,509	24,284	32-35	7,771-8,499
Commercial	Low		6,586	34	2,239	27,001	34	9,180
	Medium		180,619	34	61,411	51,931	34	17,657
	High		51,841	34	17,626	5,760	34	1,958
Institutional	Low		33,806	34	11,494	135,444	34	46,051
	Medium		217,142	34	73,828	62,489	34	21,246
	High		48,941	34	16,640	5,429	34	1,846
Regional Total	Low	2,195,200						
	Medium	2,853,376						
	High	414,400						
Total		5,462,976			669,318-714,888[e]			511,088-549,820[e]

[a]Percentage obtained via methodology described in section 3.2 of the Benham Group report (1982).

[b]Obtained by multiplying column 3 by column 4.

[c]Obtained by multiplying column 6 by column 7.

[d]The sum of column 3 for the residential category is 1,518,999. The single family/multifamily split for this total is 1,321,529 and 197,470 acres, respectively. The sum of column 6 for the residential category is 1,291,093.. The single family/multifamily split for this total is 1,123,251 and 167,842 acres, respectively. This is based on the assumption that the national average for the single family/multifamily breakdown is 87 and 13 percent, respectively (Chapin and Kaiser 1979).

[e]The sum of the two totals presented reflects that 1,180,406 to 1,264,708 acres of land will be available for solar pond development in towns/cities >10,000 in the Atlantic Northeast region.

Table 2-2. Land-Availability Projections: Black Hills Region

			Developed Land			Undeveloped Land		
Development Category	(1) City Density Category	(2) Total Acres for Cities >10,000	(3) Developed Acres	(4) Percentage of Pond-Suitable Land[a]	(5) Total Acres of Pond-Suitable Land[b]	(6) Undeveloped Acres	(7) Percentage of Pond-Suitable Land[a]	(8) Total Acres of Pond-Suitable Land[c]
Residential[d]	Low		2,692	26-39	700-1,050	4,326	26-39	1,125-1,687
	Medium		53,066	26-39	13,797-20,696	45,205	26-39	11,753-17,630
	High		23,099	26-39	6,006-9,009	4,728	26-39	1,229-1,844
Commercial	Low		2,024	34	688	3,248	34	1,104
	Medium		8,075	34	2,746	6,879	34	2,339
	High		1,158	34	394	240	34	82
Institutional	Low		400	34	136	644	34	219
	Medium		21,919	34	7,452	18,671	34	6,348
	High		9,944	34	3,381	2,037	34	693
Regional Total	Low	48,768						
	Medium	213,632						
	High	79,872						
Total		342,272			35,300-45,552[e]			24,892-31,946[e]

[a]Percentage obtained via methodology described in section 3.2 of the Benham Group report (1982).

[b]Obtained by multiplying column 3 by column 4.

[c]Obtained by multiplying column 6 by column 7.

[d]The sum of column 3 for the residential category is 78,857. The single family/multifamily split for this total is 68,606 and 10,251 acres, respectively. The sum of column 6 for the residential category is 54,259. The single family/multifamily split for this total is 47,205 and 7,054 acres, respectively. This is based on the assumption that the national average for the single family/multifamily breakdown is 87 and 13 percent, respectively (Chapin and Kaiser 1979).

[e]The sum of the two totals presented reflects that 60,192 to 77,498 acres of land will be available for solar pond development in towns/cities >10,000 in the Black Hills region.

Table 2-3. Land-Availability Projections: Great Lakes Region

Development Category	(1) City Density Category	(2) Total Acres for Cities >10,000	Developed Land (3) Developed Acres	(4) Percentage of Pond-Suitable Land[a]	(5) Total Acres of Pond-Suitable Land[b]	Undeveloped Land (6) Undeveloped Acres	(7) Percentage of Pond-Suitable Land[a]	(8) Total Acres of Pond-Suitable Land[c]
Residential[d]	Low		271,843	15-20	40,777-54,369	106,114	15-20	15,917-21,223
	Medium		1,282,145	15-20	192,322-256,429	549,350	15-20	82,403-109,870
	High		250,842	15-20	37,626-50,168	32,243	15-20	4,837-6,449
Commercial	Low		28,507	34	9,692	10,839	34	3,685
	Medium		295,880	34	100,599	126,900	34	43,146
	High		16,941	34	5,760	2,186	34	743
Institutional	Low		18,968	34	6,449	7,262	34	2,469
	Medium		394,506	34	134,132	168,980	34	57,453
	High		28,964	34	9,848	3,826	34	1,301
Regional Total	Low	1,083,904						
	Medium	3,287,552						
	High	546,496						
Total		4,917,952			537,205-627,446[e]			211,954-246,339[e]

[a]Percentage obtained via methodology described in section 3.2 of the Benham Group report (1982).

[b]Obtained by multiplying column 3 by column 4.

[c]Obtained by multiplying column 6 by column 7.

[d]The sum of column 3 for the residential category is 1,804,830. The single family/multifamily split for this total is 1,570,202 and 234,628 acres, respectively. The sum of column 6 for the residential category is 687,707. The single family/multifamily split for this total is 598,305 and 89,402 acres, respectively. This is based on the assumption that the national average for the single family/multifamily breakdown is 87 and 13 percent, respectively (Chapin and Kaiser 1979).

[e]The sum of the two totals presented reflects that 749,159 to 873,785 acres of land will be available for solar pond development in towns/cities >10,000 in the Great Lakes region.

Table 2-4. Land-Availability Projections: Gulf Coast Region

Development Category	(1) City Density Category	(2) Total Acres for Cities >10,000	Developed Land (3) Developed Acres	(4) Percentage of Pond-Suitable Land[a]	(5) Total Acres of Pond-Suitable Land[b]	Undeveloped Land (6) Undeveloped Acres	(7) Percentage of Pond-Suitable Land[a]	(8) Total Acres of Pond-Suitable Land[c]
Residential[d]	Low		411,482	28-30	115,215-123,445	102,911	28-30	28,815-30,873
	Medium		641,607	28-30	179,650-192,482	257,709	28-30	72,159-77,313
	High		54,279	28-30	15,198-16,284	28,383	28-30	7,947-8,515
Commercial	Low		117,566	34	39,972	29,392	34	9,993
	Medium		70,342	34	73,742	28,350	34	9,639
	High		6,831	34	2,323	3,568	34	1,213
Institutional	Low		29,392	34	9,993	7,328	34	2,492
	Medium		170,527	34	57,979	68,424	34	23,264
	High		22,572	34	7,674	11,806	34	4,014
Regional Total	Low	805,248						
	Medium	2,131,584						
	High	203,904						
Total		3,140,736			501,746-523,894[e]			159,536-167,316[e]

[a]Percentage obtained via methodology described in section 3.2 of the Benham Group report (1982).

[b]Obtained by multiplying column 3 by column 4.

[c]Obtained by multiplying column 6 by column 7.

[d]The sum of column 3 for the residential category is 1,107,368. The single family/multifamily split for this total is 963,410 and 143,958 acres, respectively. The sum of column 6 for the residential category is 389,003. The single family/multifamily split for this total is 338,433 and 50,570 acres, respectively. This is based on the assumption that the national average for the single family/multifamily breakdown is 87 and 13 percent, respectively (Chapin and Kaiser 1979).

[e]The sum of the two totals presented reflects that 661,282 to 691,210 acres of land will be available for solar pond development in towns/cities >10,000 in the Gulf Coast region.

Table 2-5. Land-Availability Projections: Pacific Northwest Region

			Developed Land			Undeveloped Land		
Development Category	(1) City Density Category	(2) Total Acres for Cities >10,000	(3) Developed Acres	(4) Percentage of Pond-Suitable Land[a]	(5) Total Acres of Pond-Suitable Land[b]	(6) Undeveloped Acres	(7) Percentage of Pond-Suitable Land[a]	(8) Total Acres of Pond-Suitable Land[c]
Residential[d]	Low		158,000	25-34	39,500-53,720	147,703	25-34	36,926-50,219
	Medium		174,735	25-34	43,684-59,410	21,582	25-34	5,396-7,338
	High		23,226	25-34	5,807-7,897	23,910	25-34	5,978-8,219
Commercial	Low		34,432	34	11,707	32,179	34	10,941
	Medium		9,445	34	3,211	1,181	34	402
	High		6,550	34	1,207	6,741	34	2,292
Institutional	Low		303,128	34	103,064	284,142	34	96,608
	Medium		61,393	34	20,874	7,603	34	2,585
	High		6,240	34	2,122	6,431	34	2,187
Regional Total	Low	1,608,960						
	Medium	472,256						
	High	79,488						
Total		2,160,704			231,176-263,212[e]			163,324-180,791[e]

[a]Percentage obtained via methodology described in section 3.2 of the Benham Group report (1982).

[b]Obtained by multiplying column 3 by column 4.

[c]Obtained by multiplying column 6 by column 7.

[d]The sum of column 3 for the residential category is 355,961. The single family/multifamily split for this total is 309,686 and 46,275 acres, respectively. The sum of column 6 for the residential category is 193,195. The single family/multifamily split for this total is 168,080 and 25,115 acres, respectively. This is based on the assumption that the national average for the single family/multifamily breakdown is 87 and 13 percent, respectively (Chapin and Kaiser 1979).

[e]The sum of the two totals presented reflects that 394,500 to 444,003 acres of land will be available for solar pond development in towns/cities >10,000 in the Pacific Northwest region.

Table 2-6. Land-Availability Projections: Red River Region

Development Category	(1) City Density Category	(2) Total Acres for Cities >10,000	Developed Land (3) Developed Acres	(4) Percentage of Pond-Suitable Land[a]	(5) Total Acres of Pond-Suitable Land[b]	Undeveloped Land (6) Undeveloped Acres	(7) Percentage of Pond-Suitable Land[a]	(8) Total Acres of Pond-Suitable Land[c]
Residential[d]	Low		95,682	28-31	26,791-29,661	280,005	28-31	78,401-86,802
	Medium		275,124	28-31	77,035-85,288	743,852	28-31	208,279-230,594
	High		20,891	28-31	5,849-6,476	5,105	28-31	1,492-1,583
Commercial	Low		15,740	34	5,352	46,184	34	15,703
	Medium		39,303	34	13,363	106,264	34	36,130
	High		4,450	34	1,513	1,092	34	371
Institutional	Low		19,571	34	6,654	57,264	34	19,470
	Medium		204,377	34	69,488	552,576	34	187,576
	High		2,172	34	922	663	34	225
Regional Total	Low	1,035,520						
	Medium	2,911,360						
	High	83,968						
Total		4,030,848			206,967-218,717[e]			547,584-578,454[e]

[a]Percentage obtained via methodology described in section 3.2 of the Benham Group report (1982).

[b]Obtained by multiplying column 3 by column 4.

[c]Obtained by multiplying column 6 by column 7.

[d]The sum of column 3 for the residential category is 391,697. The single family/multifamily split for this total is 340,776 and 50,921 acres, respectively. The sum of column 6 for the residential category is 1,028,962. The single family/multifamily split for this total is 895,197 and 133,765 acres, respectively. This is based on the assumption that the national average for the single family/multifamily breakdown is 87 and 13 percent, respectively (Chapin and Kaiser 1979).

[e]The sum of the two totals presented reflects that 754,551 to 797,171 acres of land will be available for solar pond development in towns/cities >10,000 in the Red River region.

Table 2-7. Land-Availability Projections: Salt Lake Region

Development Category	(1) City Density Category	(2) Total Acres for Cities >10,000	Developed Land (3) Developed Acres	(4) Percentage of Pond-Suitable Land[a]	(5) Total Acres of Pond-Suitable Land[b]	Undeveloped Land (6) Undeveloped Acres	(7) Percentage of Pond-Suitable Land[a]	(8) Total Acres of Pond-Suitable Land[c]
Residential[d]	Low		13,499	28-37	3,780-4,995	16,316	28-37	4,569-6,037
	Medium		236,253	28-37	66,151-87,414	26,208	28-37	7,338-9,697
	High		62,258	28-37	21,168-23,036	8,288	28-37	2,321-3,067
Commercial	Low		1,772	34	603	2,144	34	729
	Medium		85,975	34	29,232	9,548	34	3,246
	High		3,664	34	1,246	493	34	168
Institutional	Low		19,770	34	6,722	23,898	34	8,125
	Medium		42,868	34	14,575	5,251	34	1,785
	High		5,950	34	2,023	796	34	271
Regional Total	Low	177,152						
	Medium	477,376						
	High	126,336						
Total		780,864			145,500-169,846[e]			28,552-33,125[e]

[a]Percentage obtained via methodology described in section 3.2 of the Benham Group report (1982).

[b]Obtained by multiplying column 3 by column 4.

[c]Obtained by multiplying column 6 by column 7.

[d]The sum of column 3 for the residential category is 312,010. The single family/multifamily split for this total is 271,449 and 40,561 acres, respectively. The sum of column 6 for the residential category is 50,812. The single family/multifamily split for this total is 44,206 and 6,606 acres, respectively. This is based on the assumption that the national average for the single family/multifamily breakdown is 87 and 13 percent, respectively (Chapin and Kaiser 1979).

[e]The sum of the two totals presented reflects that 174,052 to 202,971 acres of land will be available for solar pond development in towns/cities >10,000 in the Salt Lake region.

Table 2-8. Land-Availability Projections: Southwest Region

Development Category	(1) City Density Category	(2) Total Acres for Cities >10,000	Developed Land (3) Developed Acres	(4) Percentage of Pond-Suitable Land[a]	(5) Total Acres of Pond-Suitable Land[b]	Undeveloped Land (6) Undeveloped Acres	(7) Percentage of Pond-Suitable Land[a]	(8) Total Acres of Pond-Suitable Land[c]
Residential[d]	Low		217,135	17-36	36,913-78,169	61,060	17-36	10,380-21,982
	Medium		1,022,192	17-36	173,773-367,989	340,661	17-36	57,912-122,638
	High		139,199	17-36	23,664-50,112	10,032	17-36	1,705-3,612
Commercial	Low		30,822	34	10,480	8,671	34	2,948
	Medium		80,341	34	27,316	26,850	34	9,129
	High		11,201	34	3,808	815	34	1,295
Institutional	Low		30,530	34	10,380	8,161	34	2,775
	Medium		149,354	34	50,780	49,715	34	16,903
	High		34,772	34	11,823	2,501	34	850
Regional Total	Low	728,640						
	Medium	2,097,664						
	High	271,872						
Total		3,098,176			348,937-610,857[e]			103,897-218,229[e]

[a]Percentage obtained via methodology described in section 3.2 of the Benham Group report (1982).

[b]Obtained by multiplying column 3 by column 4.

[c]Obtained by multiplying column 6 by column 7.

[d]The sum of column 3 for the residential category is 1,378,526. The single family/multifamily split for this total is 1,199,318 and 179,208 acres, respectively. The sum of column 6 for the residential category is 411,753. The single family/multifamily split for this total is 358,225 and 53,528 acres, respectively. This is based on the assumption that the national average for the single family/multifamily breakdown is 87 and 13 percent, respectively (Chapin and Kaiser 1979).

[e]The sum of the two totals presented reflects that 452,834 to 829,086 acres of land will be available for solar pond development in towns/cities >10,000 in the South West region.

Table 2-9. Land-Availability Projections: Tennessee Valley Region

Development Category	(1) City Density Category	(2) Total Acres for Cities >10,000	Developed Land (3) Developed Acres	(4) Percentage of Pond-Suitable Land[a]	(5) Total Acres of Pond-Suitable Land[b]	Undeveloped Land (6) Undeveloped Acres	(7) Percentage of Pond-Suitable Land[a]	(8) Total Acres of Pond-Suitable Land[c]
Residential[d]	Low		299,460	41-46	122,779-137,752	378,126	41-46	155,032-173,938
	Medium		770,122	41-46	315,750-354,256	111,242	41-46	45,609-51,171
	High		36,694	41-46	15,045-16,879	2,172	41-46	891-999
Commercial	Low		88,077	34	29,946	257,716	34	87,623
	Medium		81,725	34	27,787	27,458	34	9,336
	High		4,750	34	1,615	106,805	34	36,314
Institutional	Low		1,689	34	574	86,381	34	29,370
	Medium		319,118	34	108,500	11,199	34	3,808
	High		9,243	34	3,143	21,723	34	7,386
Regional Total	Low	1,206,528						
	Medium	2,162,048						
	High	232,832						
Total		3,601,408			625,139-680,452[e]			375,369-399,905[e]

[a]Percentage obtained via methodology described in section 3.2 of the Banham Group report (1982).

[b]Obtained by multiplying column 3 by column 4.

[c]Obtained by multiplying column 6 by column 7.

[d]The sum of column 3 for the residential category is 1,106,276. The single family/multifamily split for this total is 962,460 and 143,816 acres, respectively. The sum of column 6 for the residential category is 491,540. The single family/multifamily split for this total is 427,640 and 63,900 acres, respectively. This is based on the assumption that the national average for the single family/multifamily breakdown is 87 and 13 percent, respectively (Chapin and Kaiser 1979).

[e]The sum of the two totals presented reflects that 1,000,508 to 1,080,397 acres of land will be available for solar pond development in towns/cities >10,000 in the Tennessee Valley region.

Table 2-10. Comparison of Regional Land Use and Land Availability: Total Values and Residential Data

Region	Total City Acreage		Total PSL[b]		Undeveloped PSL		Undeveloped Single Family/Multifamily PSL			
	Millions of Acres	Rank[a]	Acres	Rank[a]	Acres	Rank[a]	SF[c] Acres	MF[d] Acres	SF Rank[a]	MF Rank[a]
Alaska	--	--	--	--	--	--	--	--	--	--
Atlantic Northeast	5.50	1	1,180,406-1,264,708	1	511,000-550,000	1	359,440-393,138	53,709-58,745	1	1
Black Hills	0.34	9	60,192-77,498	9	24,892-31,946	9	12,273-18,410	1,834-2,751	8	9
Great Lakes	4.90	2	749,158-813,785	4	211,954-246,339	4	89,746-119,661	13,410-17,880	4	5
Gulf Coast	3.10	5	661,282-691,210	5	159,536-167,316	6	14,761-101,530	14,160-15,171	7	4
Hawaii	--	--	--	--	--	--	--	--	--	--
Pacific Northwest	2.20	7	394,500-444,003	7	163,324-180,791	5	42,020-57,147	6,279-8,539	6	7
Puerto Rico	--	--	--	--	--	--	--	--	--	--
Red River	4.00	3	754,551-797,171	3	547,584-578,454	2	250,655-277,511	37,454-41,467	2	3
Salt Lake	0.78	8	174,052-202,971	8	28,552-33,125	8	12,378-16,356	1,850-2,444	9	8
Southwest	3.00	6	452,834-829,086	6	103,897-218,229	7	60,898-128,961	9,099-19,270	5	6
Tennessee Valley	3.60	4	1,000,508-1,080,397	2	375,369-399,945	3	175,332-196,714	26,199-29,394	3	2

[a]Highest to lowest.

[b]Pond-suitable land.

[c]Single family.

[d]Multifamily.

Table 2-11. Comparison of Regional Land Use and Land Availability Commercial and Institutional Data

Region	Undeveloped Commercial PSL[a]		Undeveloped Institutional PSL	
	Acres	Rank[b]	Acres	Rank[b]
Alaska	c	c	c	c
Atlantic Northeast	28,795	4	69,143	3
Black Hills	3,525	9	7,260	9
Great Lakes	47,574	3	61,223	4
Gulf Coast	20,845	5	29,770	6
Hawaii	c	c	c	c
Pacific Northwest	13,635	6	101,378	2
Puerto Rico	c	c	c	c
Red River	52,204	2	207,271	1
Salt Lake	4,143	8	10,181	8
Southwest	13,372	7	20,528	7
Tennessee Valley	133,273	1	40,564	5

[a]Pond-suitable land.

[b]Highest to lowest.

[c]Information not available.

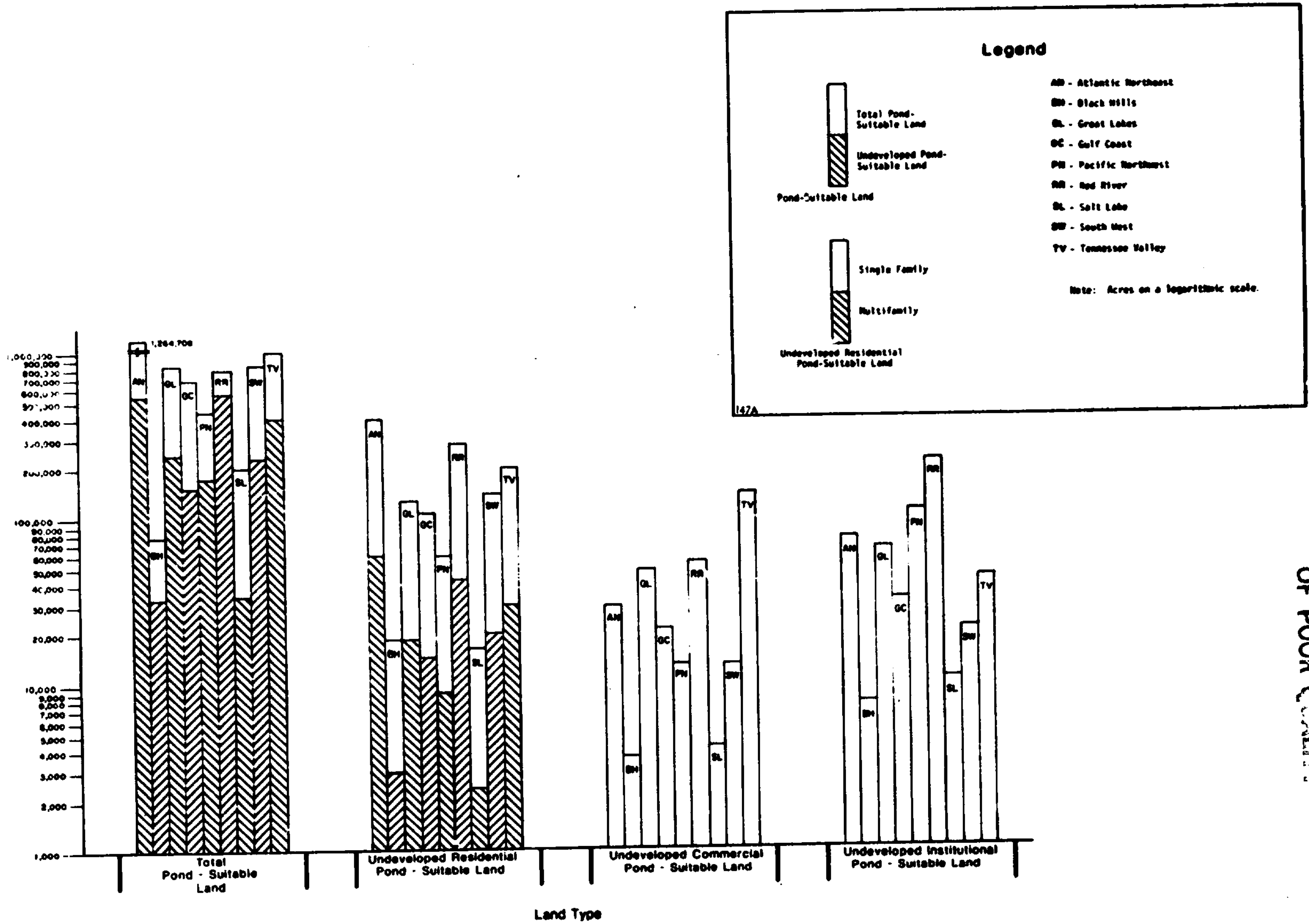

Figure 2-2. Regional Comparisons of Pond-Suitable Land

Table 2-12. Comparison of Regional Land Values

Region	Residential[a]				Commercial[a]				Institutional[a]			
	Low	Rank[b]	High	Rank[b]	Low	Rank[b]	High	Rank[b]	Low	Rank[b]	High	Rank[b]
Alaska[c]	$4,000	--	$25,000	--	$217,800	--	$1,742,000	--	$217,800	--	$1,742,000	--
Atlantic Northeast	3,049	4	46,000	2	20,000	3	144,619	1	1,000	2	90,000	2
Black Hills	28,000	7	104,544	3	108,900	6	435,600	4	12,000	6	435,600	6
Great Lakes	2,000	1	116,000	5	2,000	1	150,000	2	2,000	3	150,000	3
Gulf Coast	2,000	1	22,000	1	20,000	3	217,800	3	10,000	5	54,000	1
Hawaii[c]	261,360	--	1,176,120	--	348,480[d]	--	--	--	348,480[d]	--	--	--
Pacific Northwest	11,000	6	600,000	9	65,340	5	6,534,000	8	65,340	8	6,534,000	9
Puerto Rico	--	--	--	--	--	--	--	--	--	--	--	--
Red River	2,500	2	114,345	4	21,780	4	457,300	5	8,000	4	457,300	7
Salt Lake	29,000	8	290,000	7	155,000	7	653,400	6	20,000	7	525,000	8
South West	3,500	5	348,480	8	7,500	2	653,400	6	200	1	348,480	5
Tennessee Valley	2,614	3	186,872	6	21,780	4	871,200	7	10,000	5	261,360	4

[a]Reported as cost per acre.

[b]Lowest to highest.

[c]Not ranked; data analyzed for only one city.

[d]Medium value.

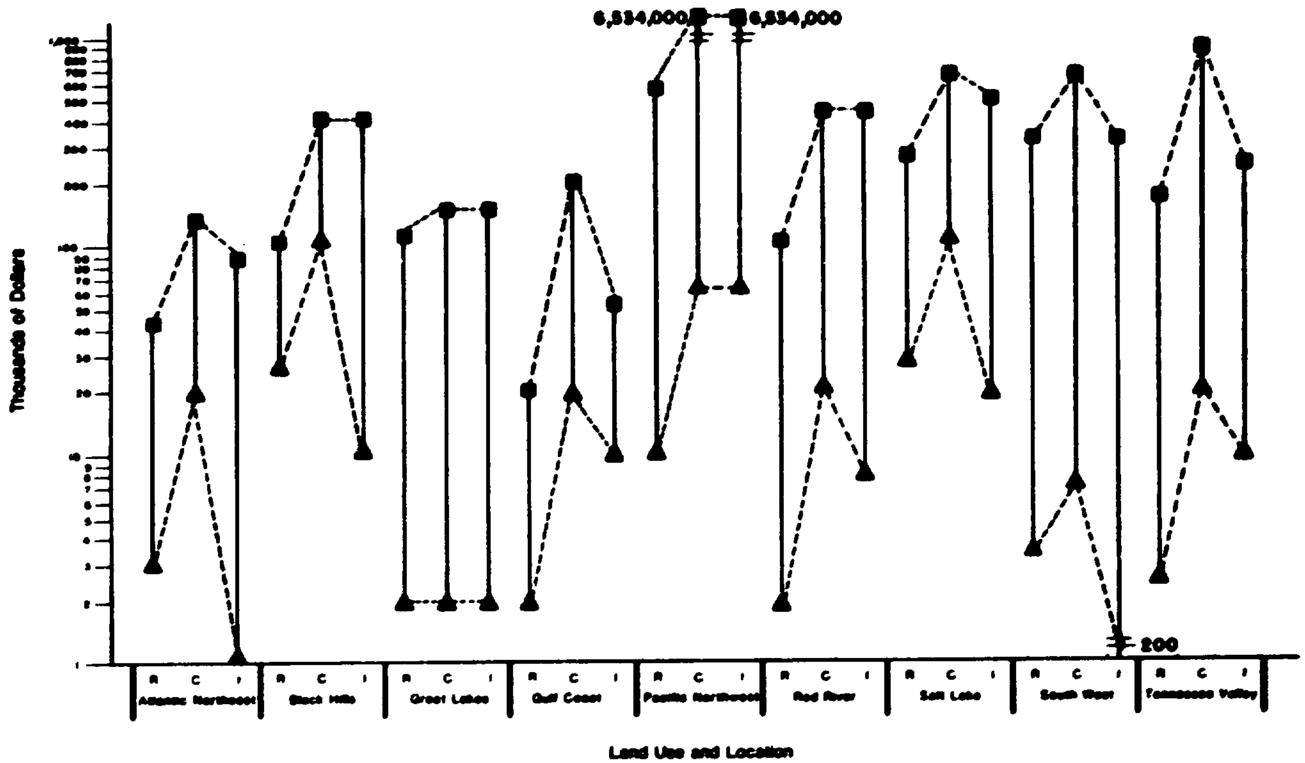

Figure 2-3. Comparisons of Regional Land Values (per acre)

Table 2-11 depicts regional totals and comparisons of the undeveloped commercial and institutional PSL. Regarding commercial lands, the Tennessee Valley region potentially has available the most land for commercial development, with the Red River and Great Lakes a distant second and third respectively. The Black Hills region is again the lowest. Potential institutional development seems to be most attractive in the Red River, the Pacific Northwest, and the Atlantic Northeast regions, respectively.

An overall visual perspective of the phenomena described in the previous paragraphs is presented in Figure 2-2. This graph reflects the data shown in Tables 2-10 and 2-11 and enables the reader to better compare the results. The dominance of the Atlantic Northeast and Tennessee Valley regions in the total PSL category is evident. In the undeveloped residential (single family/multifamily) PSL class, the Atlantic Northeast, Red River, and Tennessee Valley regions lead the rankings. Trends exhibited in the undeveloped commercial and institutional PSL categories are quite discernible.

Land-value data are difficult to obtain and evaluate because of the variety of sources from which they originate. Statistics, by nature, when examined closely, will usually present some inconsistencies and varied degrees of accuracy. Determining land values is difficult and open to individual interpretation. Other factors that influence these data include (Homer Hoyt Institute 1981):

(1) Demand variations for land.

(2) Topography and local geography.

(3) Zoning.

(4) Availability of urban services.

(5) Availability of utilities.

The three principal items affecting housing production include land, residential construction costs, and financing. These three items all increased significantly in the 1970s, and at a higher rate than in the 1960s (Miller 1981). A developed lot in today's market is now responsible for 20 to 30% of the actual cost of a single family house (FHA financed). A recent survey undertaken by the Urban Land Institute (ULI) indicates that residential land prices are continuing to increase rapidly, far exceeding the rates of consumer price increases (Miller 1981). This regional study of the United States, which divided the country into three regions (North, South, and West), indicates a large range of price increases across regions, especially in the western cities of Phoenix, Boulder, Seattle, and San Diego (Miller 1981).

Land-price inflation is affected by three basic factors: supply forces, demand forces, and future expectations of supply and demand. Those forces of supply include limits on developable land supplies, more site development requirements, and approval process delays. Demand forces include a large and strong housing demand caused by population movement and the recent invasion of the housing market by the baby boom generation. The third factor, future expectations, concerns land investments that are attractive in the speculative market in areas where increasing housing demand and rising land prices are proven commodities (Miller 1981).

The 1980 ULI survey characterizes residential land-price increases as mild in the South (Atlanta, Miami, Jacksonville, and Houston), steady in the North (Pittsburgh, Hartford, Kansas City, and Indianapolis), and accelerating in the West. In general, the survey indicates inflated residential land values are primarily influenced by the demand for new housing, higher development costs, and constraints on the supply of developable land (Miller 1981).

A recent (August 1981) projection by the Homer Hoyt Institute (HHI) indicates that in the near future (12 to 24 months) land prices will stabilize due to slow housing sales and bankruptcies. Homer Hoyt Institute states that as inflation comes down, land quickly becomes an overrated investment.

Table E-1 of Appendix E summarizes the average size of finished residential lots by states from 1976 to 1980, and Table E-2 reflects the cost of finished residential lots by states and the average cost of finished residential lots/ft^2 for the same period. These data indicate that the average cost for a finished residential lot for 1980 was $13,539, based upon 12,807 ft^2/lot ($1.05/$ft^2$). Hawaii exhibits the most expensive lots ($62,516/5,901-$ft^2$ lot) with California rated as the second most expensive ($30,853/8,378-$ft^2$ lot). Large lots are representative of the New England states (Maine: 42,168 ft^2), and small lots are most common in the west (Hawaii: 5,901 ft^2, Nevada: 7,352 ft^2, Alaska: 8,071 ft^2, and California: 8,378 ft^2).

Table E-3 of Appendix E shows a land-price index for different portions of the country based on a monthly analysis. Increases in all regions are easily traced since 1979. The increases in the Northeast have been steady and minimal, whereas the South and West exhibit steady but high increases. The lower chart of exhibit C compares the cost per acre of residential land from 1971 to 1980.

Table 2-12 presents an overall summary of the regional land values. As previously expressed, land values are difficult to obtain and are not easily compared due to the many variables involved. Based on the city-specific research of these data, the lowest residential land prices are potentially available in the Gulf Coast, Great Lakes, Red River, and Tennessee Valley regions ($2,000 to $2,614/acre). In the commercial sector, the Great Lakes and Southwest regions rank one and two, respectively, concerning the lowest potential costs based on ranges of values. Institutional prices are quite variable, but low prices are evident in the Southwest, Atlantic Northeast, and Great Lakes regions.

Figure 2-3 graphically summarizes the regional trends displayed by Table 2-12. In general, it easily is seen that land values in those areas west of the Mississippi River reflect a higher level than those areas east of the Mississippi River. These results concur with the results of the ULI and HHI studies. High values are evident in the Pacific Northwest, Black Hills, Salt Lake, Southwest, Red River, and the Tennessee Valley regions.

Examining Tables 2-10, 2-11 and 2-12 (or equivalently Figs. 2-2 and 2-3), several remarks can be made on the solar-pond land resources in the 12 regions of the United States. In general, approximately 7 to 8% of the land in the conterminous United States that is within the jurisdiction of cities having more than 10,000 people can be considered as undeveloped PSL.

The Red River region maintains the highest percentage (12%), followed closely by the Tennessee Valley (10 to 11%) and Atlantic Northeast (9 to 10%) regions. Those regions on the lower end of the spectrum include the Southwest (3 to 7%), Salt Lake (4%), and Great Lakes (4 to 5%).

Of this total undeveloped PSL in the United States, about 60% is potentially committed to residential uses. Leading the way is the Gulf Coast region (68 to 70%), while the Southwest and Atlantic Northwest regions maintain 67 to 68% and 60 to 61%, respectively. The Great Lakes region reflects a residential percentage of 49 to 56 that is the lowest reasonable percentage presented. The Pacific Northwest exhibits only a 30% residential makeup of undeveloped PSL, but as noted in the Benham Group report, these data may be distorted due to the high percentage of institutional land in Klamath Falls, Oregon. Undeveloped commercial PSL in general maintains a relatively low percentage, although the Tennessee Valley region shows 36% potentially dedicated to commercial uses.

The Atlantic Northeast, Great Lakes, Tennessee Valley and Red River regions possess the most pond-suitable land in the buildings sector. Initially this may seem surprising. However, further investigation indicates that these regions are older (historically), are more established from a development perspective, have a much higher density of cities and, consequently, more land area. In applying the various percentage analyses, the higher the number of total acres in a region the greater the potential for large pond-suitable land acreage. Overall, the Red River region exhibits the highest percentage of undeveloped PSL (12%).

Although the eastern regions predominantly show the highest land availability, the western regions still may show the most solar pond potential due to a variety of factors. In the western regions, the land surrounding the cities is predominantly open and uncongested. Raw undeveloped land is readily available, easily accessible, and ripe for annexation. Topography and vegetation are better suited to development opportunities. With the increased pursuit of natural resources for energy development west of the Mississippi River, and the attractiveness of the western sunbelt, economic and demographic changes in the western regions will almost certainly be dynamic. The resulting growth, bolstered economies, and changes in planning philosophies would cause annexation to becomes a big issue and towns/cities begin to expand. This continued trend would make the western regions a more attractive area for future solar pond development.

Collecting consistent and valid land-value data is difficult. Sources of information vary, and the presentation and type of data are inconsistent. Differing interpretations of terms (undeveloped land, raw land, etc.) lead to many data variables. Data presented herein exhibit a wide range because land costs are as low as $200 per acre (Carlsbad: institutional) and as high as $6 million (Seattle: commercial). Trends revealed here are consistent with recent land value surveys conducted by the Urban Land Institute and the Homer Hoyt Institute. Cost of land west of the Mississippi River is generally higher and is increasing at a fairly rapid rate. This can be attrib- uted to population migrations and the renewed interest in natural resources to supplement the nation's increased energy demand.

Overall, the undeveloped portions of cities seem to present the best opportunity for application of solar pond technology. The potential appears greatest in those areas where coordinated planning takes place in the early stages of a proposed development. Planned unit development and clustered development may provide the best avenues for the technology.

Developed areas would have to be retrofitted to utilize the service provided by solar ponds. The initial problems associated with retrofitting include politics, availability of sufficient adjacent land, and social and economic acceptance by those being served. However, retrofit uses on developed lands are still viable in certain areas and still hold a place in the pond technology. For example, information sources in Bozeman, Montana, indicate that retrofitting in developed subdivisions might be a distinct possibility since a set-aside parcel of open space is required in each development, primarily for park development. It seems that most of these areas remain vacant and could be used for other purposes. Officials in Pendleton, Oregon, visualize the municipal airport as a good location for further solar pond evaluations. Actual observations in Oklahoma City, Oklahoma, indicate the potential for locating vacant or unused land near existing developments is very good.

2.1.3 Water

The requirements for initially filling a pond, to rinse the surface and to replace water lost by evaporation all make the availability of water of crucial importance in siting a pond. Initial filling of the pond requires 5 to 18 feet of water. Evaporation requires up to 6 feet of water per year. The regions with most sunlight tend also to be regions of general water shortages.

Care must be taken to site ponds where the water supply will not be curtailed during the expected lifetime of the pond, and where the pollution of other local water supplies can be avoided. In many regions, the location and size of the pond will be constrained by the water supply. Individual small thermal power ponds will not be as tightly constrained as will larger electric power ponds.

Though ponds have a large water requirement, saline water can also be utilized and low-salinity water is adequate for makeup and rinsing. The use of brackish or saline water, unusable for most other purposes, is strongly indicated. Additional water sources, such as municipal waste water systems, may also be practical pond water supplies.

An advantage of solar ponds is that surface rinsing does not have to be a continuous process. During months of drought, rinsing can be curtailed without serious damage to the pond.

Areas of overall water surplus in the United States are indicated as the shaded portions on Figure 2-4. East of about 96° longitude, the country has an abundant water supply. The Pacific coastal and western mountains also have local areas of water surplus, but the remainder of the country west of about 96° longitude is water deficient.

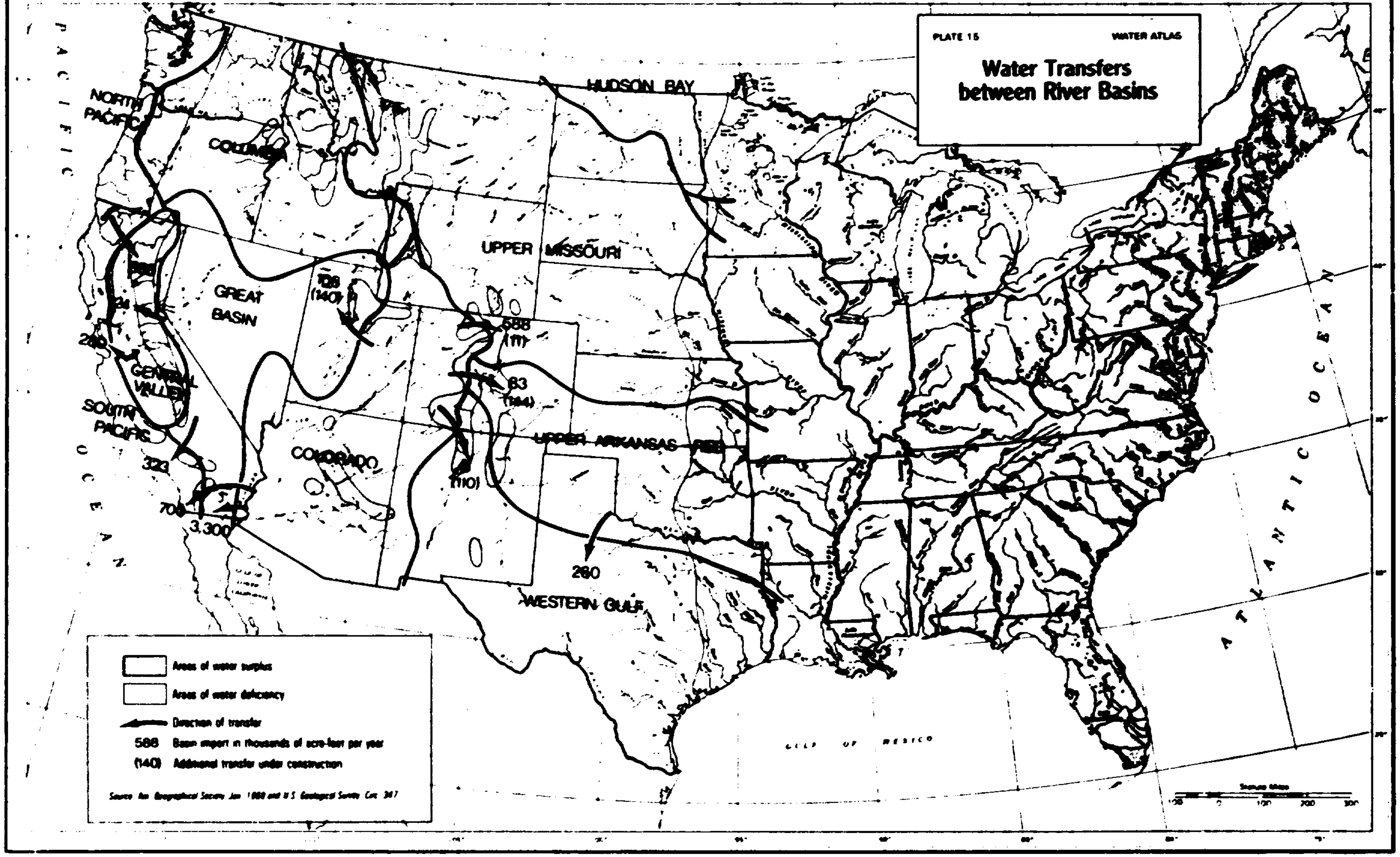

Figure 2-4. Water Surplus in the Conterminous United States, acre-feet (Source: Geraghty, et al, 1973)

A map of surface water runoff of the United States (Figure 2-5) gives an indication of the overall water supply. Surface water runoff is that portion of the annual average total precipitation which, after falling on land areas, later appears in streams through direct travel or through ground seepage. East of 90° longitude, annual runoff ranges generally from 10 to 20 in., with greater runoff in mountainous areas and in New England. Between 90 and 100° longitude, runoff decreases to approximately 1 in./yr, typical of the entire western half of the country except for certain mountain and coastal areas. On the whole, there is surplus water where more than 10 in. of annual runoff are indicated, but water is in short supply in regions with less than 5 in./yr runoff.

Naturally-occurring saline surface water is usually a nuisance because it reduces the fertility of arable land and pollutes rivers and other fresh water supplies. However, it can be advantageously utilized for solar ponds (Appendix F, Fig. F-1). Saline lakes have potential as pond sites. Table 2-13 lists the 10 largest saline lakes in the United States, with a combined area of 2707 mi^2. All of these lakes are located within or near the region of insolation greater than 4.5 kWh/m^2-day, as indicated earlier by Figure 2-1 (see also Appendix B, Fig. B-2 through B-4).

In many locations, desalination plants are used to reduce the salinity of naturally occurring water, or to clean up polluted water. Appendix F, Figure F-2, shows the locations and size ranges of the desalination plants in the United States in 1969. The brine effluent from a desalination plant is usually of little or no value, but is a source of water for solar ponds.

Groundwater, a major source of water in the United States today, is drawn from aquifers, which are sediments and hard rock beds that readily

Table 2-13 Major Saline Lakes of the United States[a]

Lake	Location	Present Area (mi^2)
Great Salt	Utah	1,000
Pontchartrain	Louisiana	625
Salton Sea	California	350
Pyramid	Nevada	180
Walker	Nevada	107
Goose	California and Oregon	100
Sabine	Louisiana and Texas	95
Calcasieu	Louisiana and Texas	90
Maurepas	Louisiana and Texas	90
Salvador	Louisiana and Texas	70
	Total	2,707

[a]Geraghty, et al, 1973.

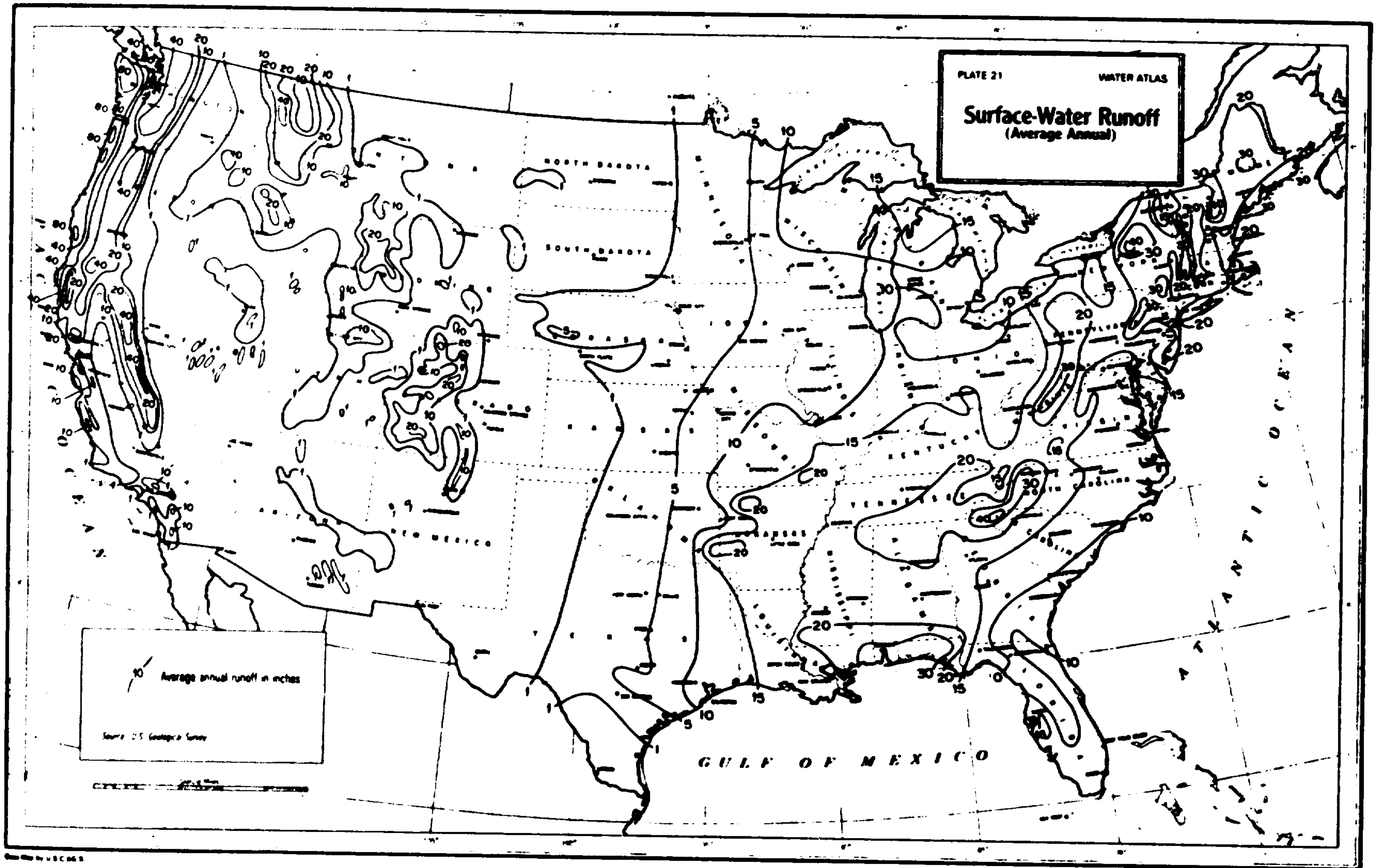

Figure 2-5. Average Annual Surface-Water Runoff in the Conterminous United States, in. (Source: Geraghty, et al, 1973)

yield water to wells and river sediments paralleling rivers (Appendix F, Fig. F-3 through F-9).

Although aquifers may contain enormous quantities of water, they are finite, and may not be naturally replenished as fast as water is withdrawn. This situation, termed "water mining," leads to diminished flow from wells and to eventual depletion of the aquifer, and can cause surface subsidence.

Groundwater is often pumped for use as drinking water where surface waters are polluted. On the other hand, many aquifers have been polluted by seepage from the surface or by encroachment of salt water into aquifers as their fresh water is depleted. Care must be exercised in solar pond siting, construction and operation to protect aquifers underlying the pond.

Saline groundwater typically underlies fresh groundwater, resides in older sediments, and increases in salinity with depth (Appendix F, Fig. F-10). The saline aquifers extending from Texas to North Dakota are partly composed of beds of salt, yielding highly saline water.

The projected water supply and demand in the year 2000 is shown on the map in Figure 2-6. The 17 water resource regions represent principal drainage basins. The upper number printed in each region indicates the region's annual average total runoff, in billions of gallons per day. Attempting to capture and use all of the runoff in a given basin is rarely feasible because most streams cannot be lowered beyond certain limits without compromising other uses such as habitat for wildlife, heat sinks for power plants and industry, navigation, recreation, and waste disposal. However, much of the water supply can be, and is, used many times if it is returned to the stream in condition acceptable to downstream users. The lower left-hand number is the total usage projected for the year 2000, in billions of gallons per day. The usage figures include all uses where water is withdrawn from the stream, and reused water is counted each time it is withdrawn. The figures do not include non-consumptive withdrawals for hydroelectric generation, which alone total more than twice the total runoff of the entire country. The lower right-hand number is the total consumptive use projected for the year 2000, in billions of gallons per day. This quantity is not returned to the stream, but evaporates from irrigated fields, is used for steam production, incorporated into products, or is otherwise permanently removed from the available water supply.

Interpreting Figure 2-6, by the year 2000 total water demands will exceed total runoff in several regions in the Southwest and around the Great Lakes. In the Rio Grande region, consumptive use will approximately equal the total runoff.

Some water-short regions are already importing water from areas of local surplus. A portion of this activity is indicated in Figure 2-4. Water transfer between river basins is shown by arrows, with figures denoting volumes in thousands of acre-feet per year (1000 acre-feet per year = 0.89 million gallons per day).

A regional summary of water supply conditions for both surface and ground water, from 1979 to 1990, is presented in Table 2-14 (Dobson and Shepard, 1979). The water resource regions are those defined in Figure 2-6.

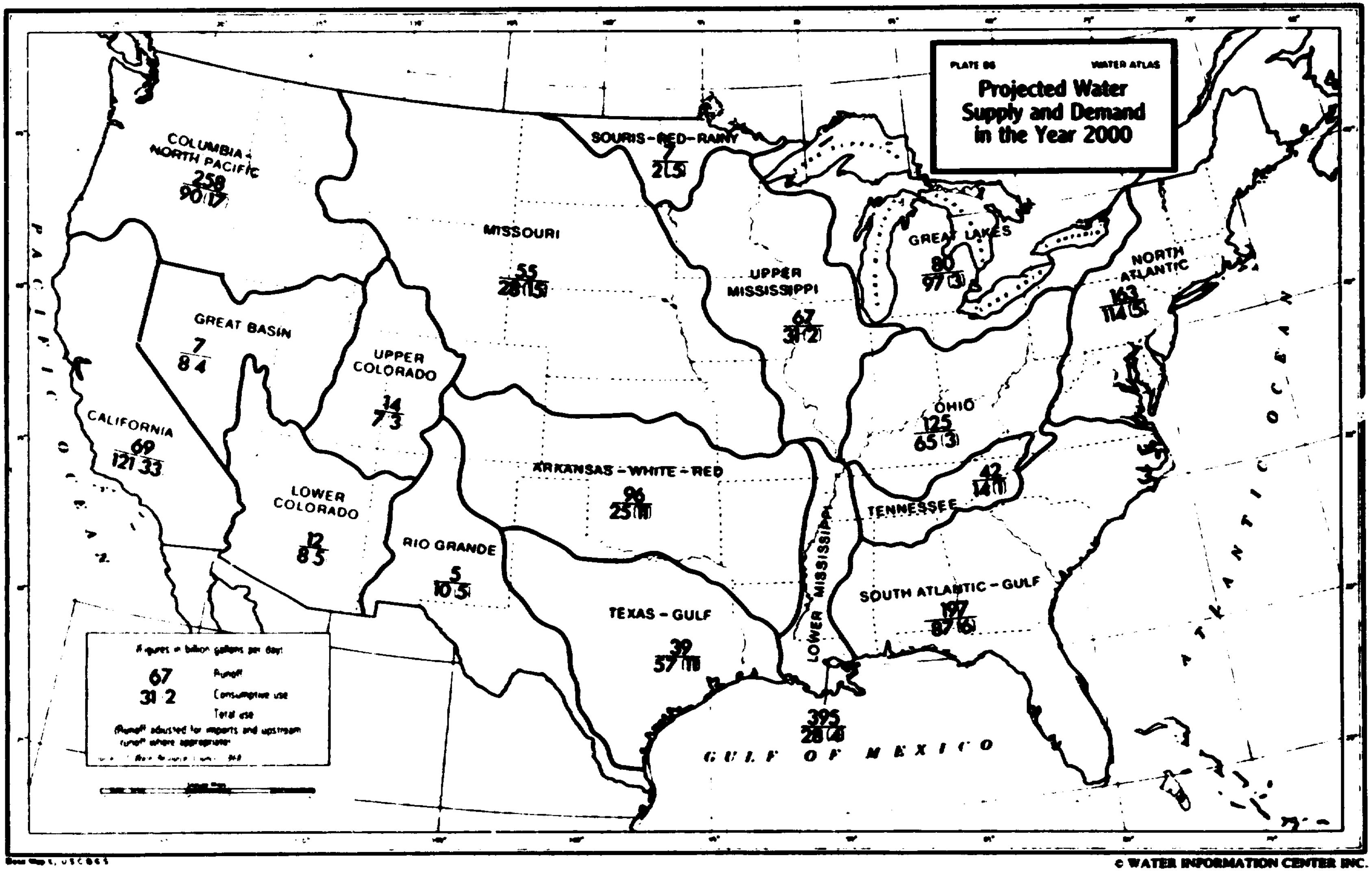

Figure 2-6. Projected Water Supply and Demand of the Conterminous United States in the Year 2000, 10^9 gal/day (Source: Geraghty, et al, 1973)

Table 2-14. Summary of U.S. Water Supply Characteristics from 1979 to 1990[a]

Water Resource Region	Surface Water Supply	Groundwater Supply
North Atlantic	New England: Local problems during low-flow periods Coastal sites preferred for power plants	6% of total usage Aquifers generally unproductive
	Middle Atlantic: Supply problems on several major rivers Increased dependence on saline water for cooling Possible widespread low-flow supply problems	10% of total usage Relatively undeveloped
South Atlantic-Gulf	Major load centers in head-water areas have low-flow problems during periodic droughts Other headwater areas may be subject to supply problems Several large rivers are relatively unused Southern Florida faces severe shortages	13% of total usage Development in southern Florida limited by local geology
Great Lakes	Ample supply overall Crowding may cause local problems Some local water shortages Consumption of Great Lakes water limited by St. Lawrence River flow requirements	4% of total usage
Ohio	Possible local shortages during low flow Substantial new energy development threatens to create a supply problem	5% of total usage Relatively undeveloped Ample reserves below 500 feet Reservoirs north of the Ohio are more productive than those to the south
Tennessee	No supply problems seen	2% of total usage Several productive reservoirs

[a]Based on Dobson, J.E., and Shepherd, A. D., "Water Availability in 1985 and 1990," ORNL/TM-6777, October 1979, pp. 3-29 to 3-52.

Table 2-14. (Cont'd)

Water Resource Region	Surface Water Supply	Groundwater Supply
Upper Mississippi	No supply problems seen	Good availability Small portion of reserves now tapped
Lower Mississippi	No supply problems seen	22% of total usage Vast underground reserves
Souris-Red-Rainy	Severe water shortages projected Critical local water shortages Development of lignite reserves will require additional water	Good potential in certain areas
Missouri	Generally ample supply, but varies from year to year Entire region may have severe problems during critical low flow Large surface reservoir capacity Coal and lignite development will require additional water	
Arkansas-White-Red	Severe shortages during critical low flow Supplies insufficient to satisfy existing demands in many areas Shortages even in normal water years	50% of total usage Principally from Oglalla aquifer, which is being systematically depleted
Texas-Gulf	General supply and quality problems Energy production will be a major contributor to problems	One third of total usage General supply and quality problems Significant reservoirs under 80% of region Twelve important aquifers Supply problems in at least two major aquifers Saline water boundaries of some aquifers preclude development

Table 2-14. (Concluded)

Water Resource Region	Surface Water Supply	Groundwater Supply
Rio Grande	Severe shortages over most of region	25% of total usage Large, extensive aquifers, many of poor water quality
Upper Colorado	Severe shortages during low-flow periods Negligible water for energy development	Shallow wells generally have low productivity Total groundwater not estimated possibly many times the shallow reservoir capacity
Lower Colorado	Severely deficient in water	40% of total usage, expected to diminish as aquifers are depleted Large overdrafts
Great Basin	Severe shortages throughout most of region	Not yet significantly developed Large storage indicated Water mining prohibited in Nevada
Columbia-North Pacific	No general supply problems seen Local shortages, especially in late summer	Supplies obtainable from several types of rock Well yields range from generally small to locally large
California-South Pacific	Severe water shortages over much of region	Major source for Central and south-central coast Large overdrafts Southern California has local overdrafts and local quality problems

Dobson and Shepherd (1979) predicted that, on the whole, energy development will encounter siting conflicts among competing users in numerous water resource regions. Selection of sites to fit local and regional priorities, use of technologies that consume less water, and development of alternative water sources will be a necessary part of the planning process. Several studies have shown that competing water uses, especially irrigation, have significant potential for conflict with energy development throughout the western United States. Conflicts may be resolved by outright purchase of water rights from the present owners, but the national need for greater energy supply may be in conflict with local and regional goals for land and water use.

In many regions, development of fossil fuel reserves, mining, and transporting and generating power from coal and lignite, are expected to put high demands on local and regional water supplies. In the East, water shortages on certain tributary and coastal rivers are expected, and problems may develop on some main rivers by 1990.

Simultaneous population and economic growth, both region-wide and centered around local energy developments, will put additional strain on the available water supplies. Domestic and industrial uses traditionally have priority over other uses.

In all parts of the country, surface water laws are based upon either the riparian doctrine, the appropriation doctrine, or a combination of the two. Riparian water rights are based upon ownership of the adjacent land, regardless of whether or not the water is used. Appropriation rights are based upon use of the water for some benefit, so that the first to use the water has priority over later users, regardless of land ownership. States with water surplus typically allow the riparian doctrine. The eight mountain states follow the appropriation doctrine. Other states follow both doctrines, but vary considerably as to the relative importance placed upon each doctrine (Appendix F, Fig. F-11).

Groundwater rights are in part similar to surface water rights. (Appendix F, Fig. F-12). Many eastern states use the English common-law riparian doctrine, giving absolute groundwater rights to the landowner. The rule of reasonable use, which restricts the rights of the landowner to reasonable use relative to other users. Correlative rights, given in California, also provide for correlation between the landowner's use and other users during times of shortage. The appropriation doctrine is followed in 13 states, but with some difficulty due primarily to misunderstandings of the nature of the resource (Geraghty, et al, 1973).

Regulation of surface and groundwater use is increasing. Water availability has recently been revived as a national issue, while pollution of surface and groundwater, and other water/environment, impacts, have been regulated for the past decade.

2.1.4 Salts and Brines

Salts or high-salinity brines are used to construct and maintain the salt gradient in a salt-gradient solar pond. Normally, 2000 to 4000 tons of salts are required for a 1-acre pond, depending on its depth. For smaller ponds which are intended for thermal applications, salt purchase may be feasible, in which case ponds need not be located where salts or brines are locally available. However, for larger ponds which are intended for electric power production, economic considerations usually favor pond sites that possess sufficient salt resources. Ocean water or low-salinity brines may be utilized if time is allowed to produce more concentrated brine from these via processes such as evaporation. Salts are not limited to sodium chloride or magnesium chloride; they can be a combination of a number of solids that are nontoxic, adequately soluble in water (preferably with a solubility that increases with temperature), and whose solution is sufficiently transparent or can be treated to obtain transparency.

The United States has an abundance of salt reserves in several areas as indicated in Figure 2-7. This section addresses each state as to the availability of salts or brines as they relate to solar ponds. Some states are more detailed than others, depending on the availability of information. Most are generalized due to the scope of this report and the geographical area covered. Information pertaining to the availability of clay or any other mineral and remarks pointing out potential pond sites are also included when appropriate (Hurick, 1981).

Alabama. Southwestern Alabama encompassing Choctaw, Clarke, Washington, Wilcox, Monroe, Escambia, Baldwin, and Mobile Counties is underlain by the Louann Salt at depth. The shallowest depth to the Louann Salt is about 8200 ft below the surface. However, in Washington and Clarke Counties there are salt domes. The shallowest are the Klepac and McIntosh Domes. The McIntosh Dome is 410 ft below the surface. Brine is also found in this same area. Much of the brine is associated with oil and gas recovery. The brine is also associated with marine formations along the coast. The coastal area of Alabama may offer some good sites.

Clay in Alabama is adequate for pond lining. The clay is found throughout the state and is found in-place in the same area as is underlain by salt.

Alaska. The state of Alaska contains no known salt deposits. Coastal areas of southern Alaska may provide some opportunity for evaporation of seawater.

Arizona. Arizona has three areas that are of interest as potential power generation sites. These are the Supai Basin, also known as the Holbrook Basin; Maricopa County west of Phoenix; Haulpai and Detrital Valleys.

The salt deposits in the Supai Basin (Navajo and Apache Counties) are at depths varying from 650 ft in the western part of the basin to 1500 ft in Apache County. The thickness of the beds range from 50 to 100 ft with total thickness around 550 ft. Indications are that the principal concentrations of salt occur along a northeast trending zone between Snowflake, Arizona, and Pinta Dome in Apache County, a distance of 55 miles. Portions of the basin lie within the Petrified Forest National Park and is therefore closed to consideration. However, most of the basin lies outside of National Park boundaries.

The salt deposit west of Phoenix is at a depth of 880 ft and is estimated to be 10,000 ft thick. The proximity to Phoenix may make this an ideal site. The deposit is within 20 mi of Phoenix.

The third area is in northwestern Arizona in Mohave County. In Haulpai Valley, south of the Red Lake playa, salt was encountered at about 1400 ft below the surface during exploratory drilling and was still in salt when bottomed at about 2600 ft. This rock salt deposit is at least 1200 ft thick. In Detrital Valley, northwest cf Haulpai Valley and near Lake Mead, several holes were drilled. Salt was encountered at depths ranging between 300 and 800 ft below the surface. The penetrated salt is reported to have ranged between 500 and 700 ft thick. The proximity to Lake Mead and Hoover Dam may make this another ideal site.

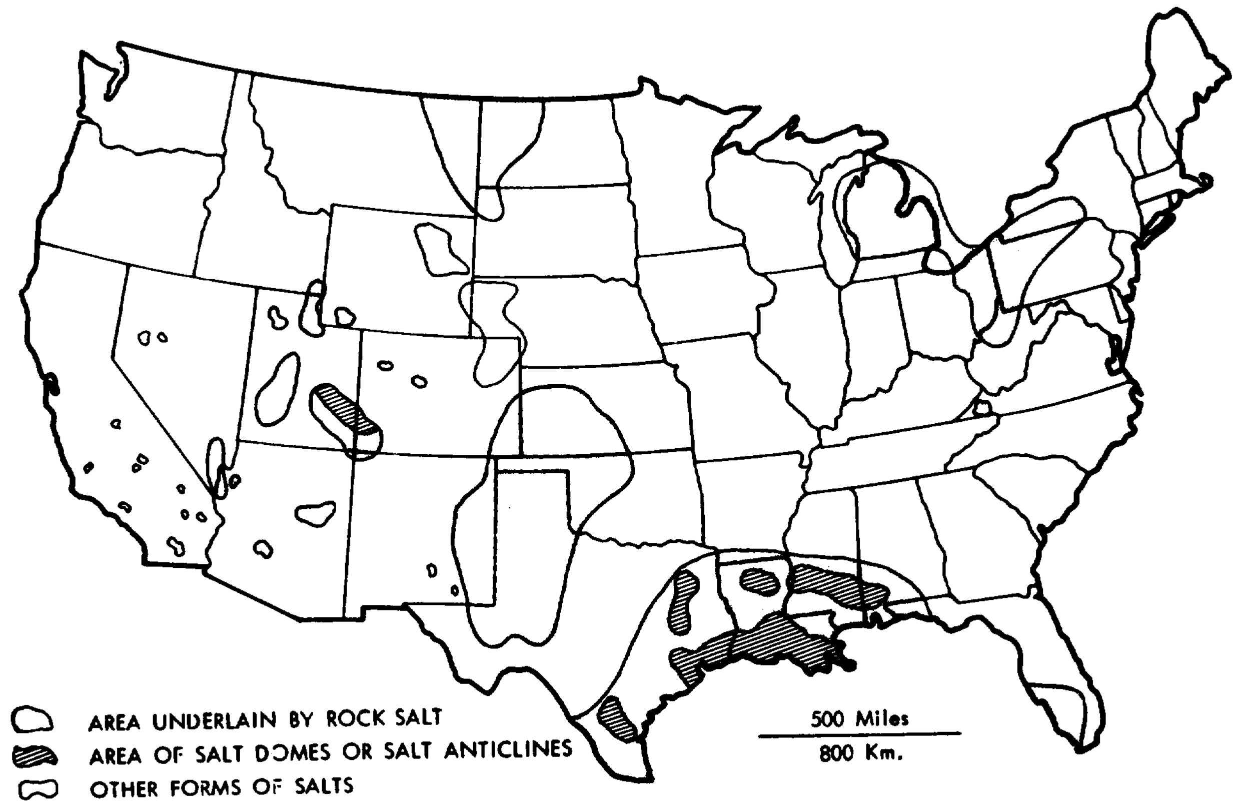

Figure 2-7. Salt Reserves of the Conterminous United States (Source: Johnson and Gonzales, 1978)

Clay exists in the same area near Phoenix as the salt deposit. Bentonite and common clay are found near and in portions of the Supai Basin and near Snowflake, Arizona, clay has been dug for bricks. There appears to be no known deposits of clay in Detrital or Haulpai Valleys, however, this is an area of playas and evaporite lakes similar to those common to southern Nevada and the California Desert.

Arkansas. The southern part of Arkansas is underlain by the Louann Salt. This bedded salt extends north from the Gulf Coast. As it enters Arkansas it trends to shallower depths than those determined in Louisiana. In Union and Columbia Counties the depth to the bedded salt may lie at 6000 ft or less. Northward from Union County the salt has been encountered at 1500 ft below the surface. In the Smackover Formation of southern Arkansas heavy brines exist. These brines vary between total dissolved solids of more than 29% to something over 37%. These brines are currently mined for bromine and the remaining brine after bromine extraction is returned to the brine table with TDS of around 30%.

Clay exists in varying quality in southern Arkansas. The clay in Union and Columbia Counties are not as good as the clay in immediate adjacent counties. A clay mix of in-situ clay with clay from the adjacent counties would make a good liner. Clay is abundant in southern Arkansas.

California. Salt occurs in California as rock salt, playa or evaporite lakes, and salt springs. The playa or evaporite lakes, rock salt, and salt springs are found mainly in the California deserts with brine associated throughout the region. However, most of the salt derived in the state is through solar evaporation of seawater. The major occurrences of inland salt are found in Inyo, Kern, Mono, San Bernardino, and Imperial-Riverside Counties. The Salton Sea which lies in Imperial-Riverside Counties is the most obvious of the playa lakes and is the current subject of study for a solar salt pond power generation site. The other major occurrences are covered by counties below.

Inyo County: Death Valley is the most well known for its evaporite basins. However, because it is also a National Monument it is precluded from this study. Deep Springs Lake in Deep Springs Valley contains brines analyzed at 8 to 20% dissolved solids, though less than half is NaCl. Owens Lake is fairly sizeable and may contain about 233 g/l of NaCl. However, much of the water in this area is diverted to Los Angeles. This should not remove Owens Lake from consideration. Saline Valley contains a playa lake known as Salt Lake. Its surface is covered with broken blocks of salt and possibly mud. About 1 mi^2 of smooth clean salt is found on the southeastern side of the lake. Reports indicate that alternating layers of mud and salines are found to a depth of 30 ft. Tecopa Basin has been reported as having salt beds, but no further information is available.

Kern County: Castac Lake at Lebec, California, is a shallow playa lake which is covered with a thick salt crust in the dry season.[3] Castac Lake has some advantages that other potential sites do not have. First, it is

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[3]Castac Lake is a natural playa lake in southern Kern County at Lebec and should not be confused with Castaic Lake, the man-made lake which, along with Hughes Lake, is part of the California Aqueduct terminus in Los Angeles County.

very accessible and is within sight of I-5. Second, it is closer to Los Angeles than any of the other sites. Third, the California Aqueduct passes very close by. Fourth, the lake is the right size for a pilot pond. However, Castac Lake has one disadvantage that none of the other potential sites have. Castac Lake lies right in the middle of the San Andreas Fault Zone and is about 3 mi or so from the junction of the Garlock Fault with the San Andreas Fault Zone. This should not remove Castac Lake from consideration, especially as a pilot pond. Koehn (Kane) Lake in Koehn Basin has produced salt through solar evaporation for surface brines. The lake is about 3 by 6 mi in area. During the spring and fall rains the lake may be submerged to a depth of 10 in. Salt Well Valley is a large area in northeastern Kern County that has many salt wells. This area is located between Indian Wells Valley and Searles Basin and the brines should not be too dissimilar to those of Searles Lake.

Mono County: Mono Lake, the highest of the saline lakes of the great Basin, and Black Lake, not far from Mono Lake have low amounts of salt in solution. Black Lake has only a minor amount of salt. Mono Lake's salt content is fairly low at 18.54 g/l of NaCl with a main constituent of $CaSO_4$. Neither lake is, at present, a desirable site. Black Lake is about 1 mi long by 500 ft wide and up to 70 ft deep with organic matter in solution. Mono Lake, presently, is ecologically delicate and is "dying." Water that used to drain into Mono Lake is being diverted to Los Angeles with the result that the lake is shrinking significantly.

San Bernardino County: San Bernardino County has more major occurrences than any other county in the state. This is not surprising considering its geographical location and extent. Bitter Lake has a spring, Bitter Spring, at its southeast end which contains sodium chloride and sodium sulfate. Bristol Lake has both sodium and calcium chloride. The calcium chloride has been recovered from brine that has seeped into excavations for salt. The salt is found in a nearby horizontal rock salt lense that has an area about 5 mi^2. Its thickness varies from about 6 to 7 ft, thinning toward the edges and covered by about 6 to 7 ft of mud. A bore hole to a depth of 1000 ft found salt beds alternating with clay. Cadiz Lake is reported to have about 26 ft total thickness of salt and gypsum mixed with clay and sand with the average thickness between 5 to 7 ft. This is covered by about 6 ft of mud and a salt crust. Dilute brines are also associated with the deposit. Cave Springs and the area around Daggett are reported to have salt, but no data is available. Dale Lake has both sodium sulfate and sodium chloride with proportions of 60 and 30%, respectively. The lake is about 5 mi^2. Both minerals are found in fairly pure bodies at shallow depth. Two salt zones exist, a 30-ft zone at a depth of 20 to 40 ft, and a 100-ft zone at about 120 ft. Danby Lake is one of the four salt-bearing dry lakes in the southeastern part of the county. It is 2 to 3 mi wide and 14 mi long. Beneath a 5-ft sticky, impervious clay layer are horizontal, tabular bodies of salt usually enclosed in a sticky gray clay. The salt varies in thickness from 5 ft or less to 15 ft and contains much interbedded clay. Brines are associated with this deposit that are strong with concentrations around 200,000 ppm.

Emerson Lake, Needles, Round Mountain, and Salt Springs at the southeastern end of Death Valley, and Saratoga Springs 14 mi northeast of Salt Springs have reported salt, but no further data is available. Searles Lake,

currently being mined by Kerr-McGee, is a mud and sand salt flat with an exposed salt area of about 13 mi^2 with additional bodies buried in a 20 mi^2 area surrounding the exposed main body. The upper or main salt body averages 71 ft thick with saturated brine in interstitial equilibrium with soluble salts. The second salt body is about 35 ft thick and separated from the main body by 10 to 15 ft of impervious mud. The salt bodies outside the main area are as thick as 30 ft. Soda Lake is covered during the wet season by a thin sheet of sodium chloride-sulfate brine covering an area about 80 mi^2. During the dry season the area is covered by a thin saline crust. There are no known salt beds in the lake bed. Valley Springs located about 8 mi northwest of Saratoga Springs contains about 1800 g/l of NaCl. Willard Lake has a surface impregnated with salt, but no further data is available.

Those sites previously mentioned have been inland areas. The coastline affords a few opportunities. These are San Francisco Bay, San Pablo Bay, San Diego Bay, and Monterey Bay. Some areas just inland from the coast may be worth a closer look, especially between Los Angeles and Morro Bay. Areas along the eastern slope of the Coast Range might also be considered. Surprise Valley, in Modoc County, with Upper, Middle, and Lower Alkali Lake is another possibility, but no analyses are available.

Colorado. Three major areas of bedded salt can be found in Colorado. The first is the Paradox Basin salt which is found in western Colorado and extends northwest-southeast into and along the Colorado-Utah border. The second is the Permian Basin salt in southeastern Colorado bordering along Kansas and Oklahoma. The third is the Lusk Embayment salt, which some authorities believe to be part of the Permian Basin, found in northeastern Colorado bordering Nebraska. All the major salt is at depth. The Lusk Embayment salt is at moderate depths about 5000 ft below the surface. The Permian salt is fairly shallow, about 1000 ft below the surface. However, in Colorado the Permian salt deposits are imperfectly known and may be thinly bedded. The Paradox Basin salt lying in western Colorado lies at moderate depths ranging from about 4600 ft in Montrose County to about 8850 ft in La Plata County.

In Mesa County, probably due to folding of the Paradox members, salt was encountered at 400 ft below the surface. In Sinbad and Paradox Valleys the salt ranges in depth from 400 to 1300 ft. Each of the major reserves are extensive and have associated brines. The brines associated with the Paradox Basin bedded salts are highly concentrated. It is reported that the brines are about 230,000 ppm. Clays are also found in eastern Colorado. In the Paradox Basin clay can be found mixed with shales. However, there exists a shale that when weathered can be used as adobe, but even in its unweathered state it is impermeable and is quite suitable for ponds. The U.S. Water and Resources Office, formerly Bureau of Reclamation, is currently engaged in a project to dispose of the heavy brines of the Paradox Basin to curtail the contamination of the Colorado River drainage basin.

Connecticut. The state of Connecticut contains no known salt deposits. Coastal areas along Long Island Sound may provide some opportunity for evaporation of seawater.

Delaware. The state of Delaware does not have any reported bedded salt deposits. However, at depth there does exist saline groundwater, especially along the coast. In addition, the state, with assistance of the U.S.

Department of Energy, is considering drilling a geothermal well at Lewes, Delaware. Brines approaching 40,000 ppm are expected to be associated with this well. The site is on state university property and it is likely that land for a research or pilot pond in the size of 1 km^2 or a little larger is available. The specific site is located near the mouth of Delaware bay. The soil, though, may be fairly permeable, so a close study would be warranted.

Florida. Southern and western Florida have Louann Salt at depth. The depths to the salt exceed 10,000 ft. Brines are available within the state. The Florida coast with its estuaries, embayments, bays, and inland waterways present many areas where evaporation of seawater can occur. Almost all of Florida is within 60 mi of the coast enabling most inland areas to be considered for evaporation ponds.

Georgia. The state of Georgia contains no known salt deposits. Coastal areas along the Atlantic may provide some opportunity for evaporation of seawater.

Hawaii. The state of Hawaii has previously produced small amounts of salt through solar evaporation. The availability of land for evaporation of seawater on any of the Islands of Hawaii may be limited.

Idaho. The state of Idaho contains some bedded salts. These deposits are primarily found in Caribou County along the Idaho-Utah-Wyoming border. Brines occur within the same region. (See Wyoming for description of border area.)

Illinois. The state of Illinois contains no known salt deposits. Brines are in occurrence in moderate concentrations around Chicago and in heavier concentrations in the southern portions of the state. In southern Illinois the brines are at depths around 3300 to 6600 ft at 50,000 to 100,000 ppm. Near Chicago the brines are below about 3300 ft at 50,000 ppm. The brines of southern Illinois are usually associated with oil and gas deposits and recovery operations.

Indiana. The state of Indiana contains no known salt deposits. Brines are in occurrence in the oil producing portions of the state. Brines are more available in southwestern Indiana. Concentrations are reported to be 100,000 to 200,000 mg/l TDS lying at depths from 1800 to 6000 ft.

Iowa. The state of Iowa contains no known halite deposits. Gypsum occurs in Webster, Marion, and Des Moines Counties. Ca, $MgSO_4$ concentrations of 30,000 to 35,000 mg/l are in existence in the groundwater supply.

Kansas. Permian Basin salt is found at depth in central and western Kansas. The depth varies from about 450 ft in Clark County to about 2500 ft in Thomas County. The Permian salt is extensive within the state and some is being mined. The depth to the salt is shallow enough to be mined using room and pillar mining techniques although solution mining is probably more practicable. Brines are available in western Kansas that range in concentration from 25,000 to 160,000 ppm and vary in depth. Some clay exists, but for the most part the surface soil is a sandy loam. State regulations discourage the use of clay or other natural material for lining ponds.

Kentucky. The state of Kentucky contains no known salt deposits. Western and northeastern Kentucky have brines with reported concentrations in the upper

tens or hundreds of thousands ppm. The Kentucky Geological Survey is currently engaged in an aquifer study as part of the Underground Injection Control Program for Kentucky. Part of the task of this study is to define the fresh/saline groundwater interface.

Louisiana. The state of Louisiana has vast reserves of salt. The entire state is underlain by Louann Salt. These reserves are categorized into the Gulf Coast Group and the Inland Group. Along the Gulf Coast there are numerous salt domes most of which are associated with oil and gas production. The coastal zone consists of numerous swamps and bayous containing saline or brackish waters. Beneath these swamps and bayous and beneath the coastal zone proper are salt domes that have their roots in the mother salt, the Louann Salt Formation. There is abundant salt and water for any size solar salt pond. There are at least 22 salt domes that can easily be mined through solution mining techniques statewide. The remaining hundred or so salt domes statewide can also be tapped as most of them have oil or gas recovery processes associated with them. The Inland Group has 31 known salt domes of which seven are easily utilized. The underlying groundwater is saline and the state of Louisiana would welcome any reasonable project that would use the saline water so that fresh water can migrate into those areas where saline water is being utilized. Clay is in sufficient quantities for lining large ponds.

Maine. The state of Maine contains no known salt deposits. The state has buried inland bedrock valleys that contain "fossil" salt water. The state has over 3000 miles of ocean-fronting coast and may provide opportunities for evaporation of seawater. Clay is in sufficient quantities for ponding.

Maryland. The state of Maryland contains some bedded salts in the extreme northwestern corner of Garrett County in western Maryland. Brackish water to brines are found at depths below 500 ft in eastern Maryland. The coastal plain of eastern Maryland and the Chesapeake Bay coastline may provide opportunities for evaporation of seawater of concentrating brines.

Massachusetts. The state of Massachusetts contains no known salt deposits. Coastal areas along the Atlantic may provide areas for evaporation of seawater.

Michigan. Most of Lower Michigan with the exception of those counties along the Indiana-Ohio border is underlain by vast amounts of bedded Silurian salt of the Michigan Basin portion of the Salina Basin. In the center of the basin in Gladwin and Midland Counties over 1600 ft of salt exists at depths over 6500 ft. The maximum thickness is estimated at 2000 ft in Bay County. The salt thins toward the boundaries of the basin. Approaching Detroit from the northwest, the salt thins to about 550 ft thick and 12 miles south of Wyandotte the thickness is about 180 ft and 26 ft in Trenton. The depth to the top of the salt varies considerably. Salt lies at a depth of 800 ft near Detroit and only 500 ft along the borders of the basin. In the center salt lies at a depth of 6000 ft or more.

For development of a pond or ponds the area along the Saginaw Peninsula and Saginaw Bay would present some possible potential sites. Salt and brine are currently mined in Midland, St. Clair, and Wayne Counties.

As with other portions of the Salina Basin brines are associated and found at shallower depths than the bedded salts. The soil in the area

consists largely of glacial drift with sands and sandstones distributed throughout. Dolomite, however, is the major subsurface and outcrop constituent in the Michigan Basin portion of the Salina Basin. The surface soil contains lenticular clay deposits that are somewhat controlled by the pattern of the glacial drift. These clay deposits are scattered throughout the state.

Minnesota. The state of Minnesota contains no known salt deposits. Two areas in the state present themselves for possible consideration for potential sites. The two areas have briny or saline groundwater. The first is the upper Red River Valley in Kitson County in extreme northwest Minnesota. This area contains briny aquifers (50,000 ppm) and clay rich soils that form impermeable soils. The second is in the vicinity of the Temperance River on the north shore of Lake Superior. This area contains brackish to saline groundwater. The area though may present a problem for evaporation of saline groundwater due to the high purity of Lake Superior.

Mississippi. Mississippi has abundant salt reserves. The Gulf Coast Salt Domes extend through the southern half of the state. There are 49 relatively shallow piercement type salt domes in the state. Of these domes, 25 have their salt tops at a depth of 3000 ft or less. The shallowest salt dome is the Richton Dome in Perry County, lying about 530 ft below the surface. Most of the domes have been discovered during oil and gas exploration. The Mother Salt, the Louann Salt Formation, is at extreme depth. In addition to the salt domes much of the state is underlain by brine. Associated with oil and gas recovery is brine, much of which is discharged back into the ground.

Mississippi also has saline swamps and bayous along the Gulf Coast and embayments that may be suitable for ponding. The areas inland from the coast tend to be heavily wooded or under cultivation.

Missouri. The state of Missouri contains no known salt deposits. Salt County is reported to contain some brines, but are not thought to be sufficient or significant for power generation ponds.

Montana. The state of Montana contains bedded salts of the Williston Basin at depths around and below 6500 ft. The average thickness perhaps may exceed 200 ft. These salts are located in northeastern Montana. East of the Rockies of Montana numerous areas exist that are saline, either as saline groundwater, ponds, lakes, or drainages.

Nebraska. Western Nebraska has salt deposition at depth in Sioux, Cheyenne, and Dawes Counties. Salt can be found 3200 ft below the surface in Dawes County and 5800 to 6600 ft below the surface in Cheyenne and Sioux Counties. The thickness of the bedded salt may range from 180 ft in Dawes County to perhaps 600 ft in Sioux and Box Butte Counties.

In western Nebraska numerous small alkaline lakes can be found in Garden and Sheridan Counties. These lakes are measured in hectares and are shallow. The area, however, appears to be swampy and marshy.

The areal extent of the Lusk Embayment salts in western Nebraska is not clearly known. The counties listed above are those cited in the literature.

Nevada. Nevada is particularly well off in potential solar salt pond sites. There appears to be adequate land, salt, and water for sizeable power generation ponds. All the potential sites are naturally occurring. The state has many playa lakes that may be utilized. The sites have not been exploited with the exception of some local uses. The sites are located such that they have not attracted commercial attention, until now. The locations of the potential sites are advantageous for power generation ponds. Below is a county listing of each potential site with the available data.

Clark County: Rock salt deposits are known to exist in the Virgin River Valley a few miles north of the Colorado River. Outcrops occur at several places along the valley between St. Thomas and the mouth of the Virgin River, where it joins the Colorado River. These outcrops extend over a distance of 12 miles. Lake Mead now covers most of the outcrops except for two.

Churchill County: Salt is reported at Carson Sink, but no data is available other than a salt crust does exist. Dixie Salt Marsh, lying in the Dixie Valley, is a former playa lake. A salt crust, 1 to 5 ft thick, covers an area of about 9 mi^2 near the center of the marsh. Underlying the crust is a saline mud grading into salt and mud layers with clay. Eagle Salt Marsh has been used in the past for salt production from solar evaporation ponds using a natural brine located 20 ft below the surface. Production used shallow excavations 50 to 60 ft wide and 100 ft long on an impervious clay. White Plain-Humbolt Sink produced salt through solar evaporation of brine from salt springs. A series of vats which totalled 8500 ft in length and 55 ft in width were used. Salt incrustation covers a large portion of the Humbolt Sink and the reserves are believed to be extensive. At Parran a small quantity of salt was obtained through solar evaporation. The extent of the brine is unknown. Sand (Salt) Springs Marsh about 25 mi east of Fallon, Nevada, reports a surface of 7 ft of hard crystalline salt underlain by soft black mud. During the winter a shallow brine lake, a few inches deep forms covering 10 to 15 mi^2. During the summer the water evaporates leaving a deposit of 3 to 5 inches.

Elko County: Salt has been reported near Charleston but no data is available.

Esmeralda County: Columbus Marsh located along the border between Esmeralda County and Mineral County is a playa deposit about 9 mi long and 6 miles wide with dilute brines. Silver Peak Marsh located in central Esmeralda County in Clayton Valley is about 10 mi long and about 4 mi wide covering approximately 32 mi^2. During most rainstorms a foot of water may cover the area. Near the surface the groundwater and muds contain concentrated brines. The marsh contains a high-grade sodium chloride deposits. The chief constituents are salt, salt clays, and mud with layers of crystallined salt covered irregularly by gypsum-bearing clays. It is estimated that 15 million tons of salt lie within 40 ft of the surface. The Foote Mineral Company mined the brines in the past and may still continue to do so.

Eureka County: Salt has been found in Diamond Valley west of the Diamond Range. The plain is strongly impregnated with salt and broad fields of salt crusts are found in the upper end of the valley. About 1000 acres of the upper end has salt crust several inches thick.

Lyon County: Salt has been reported at Wabuska but no data is available.

Mineral County: Rhodes Marsh is a circular marsh about 2.5 to 3 mi in diameter covering about 5 to 6 mi^2. In the center is a layer of pure salt covering an area about 1 mi^2. Other constituent minerals occur at the edge of the center crust of salt. Teel's Marsh lies northwest of Columbus Marsh and was once the most productive borax field in the West. The surface is a soft clayey surface formed by crude borax. The areal extent is 1 to 2 mi wide by 4 mi long. The thickness of the deposit varies from 0.5 to 18 inches.

Nye County: Butterfield Marsh lies in the lowest portion of Railroad Valley and its area is about 40 mi^2. A thin salt crust of several inches covers the marsh.

Washoe County: Buffalo Springs Salt Deposit lies on the west side of Smokey Creek Desert. A lake is formed during the wet season. A crust of salt several inches thick occurs after the wet season. The lake bed is impregnated with brines that contain almost 15% NaCl.

Nevada has many unnamed lakes and playas that contain salt on which there is no information. Each of the detailed occurrences should be considered as a potential site unless otherwise indicated.

New Hampshire. The state of New Hampshire contains no known salt deposits. The coastal area of the state is limited and may present no opportunities for evaporation of seawater. The coastline, however, should not be discounted.

New Jersey. The state of New Jersey contains no known salt deposits. The coastal areas of the state along the Atlantic and Delaware Bay coasts and up the Delaware River toward Philadelphia may present areas of opportunity for evaporation seawater. In the past evaporation ponds did exist for local uses.

New Mexico. In the state of New Mexico, the southeast corner area and the central eastern portions of the state have vast reserves of salt at depth with associated brines. These deposits are part of the Permian Basin with its corresponding salt bearing formations. The depth to the salt ranges from about 400 ft in the southwestern portion of the basin to more than 2500 ft in the northern portions.

In addition to the abundant salt deposits at depth, the state of New Mexico has brine at shallow depths throughout the southeastern portion of the state. The area lies along the Pecos River and in Eddy County. Brine is also associated with Potash production in Chaves County and oil and gas production in Lea and Eddy Counties. Several evaporite deposits and salt lakes are also found in the state. These can be found in Catron, Torrance, Sierra, Dona Anna, and Otero Counties. The salt lakes in Torrance County are of more interest than the others. Numerous salt lakes cover a total of several thousand acres in Torrance County. Laguna del Perro, about 12 mi long, is the largest of the lakes.

Various types of clay are available throughout the state ranging from adobe and common clay to bentonite.

New York. Bedded rock salt underlies most of central southern New York from Pennsylvania to the southern borders of the counties along Lake Ontario. The salt is at depth and is part of the Salina Basin salt. The salt reserves are extensive and access is at fairly moderate depths. In Seneca County, salt can be found at about 300 ft below the surface. The Saline salt underlies about 8500 sq miles of New York with most of it at depths varying from about 525 ft in the north at Canandaigua to over 4500 ft at Salamanca in the southern part of the state.

The availability of brine is not known, though brines are being recovered for salt, but can be surmised as being available in the subsurface of the same geographical area as the bedded salt. Brine is associated with the Salina Basin in Ohio, Pennsylvania, West Virginia, and Michigan.

The availability of clay is also unknown. However, the geology of the area of interest is not that much different than the area of interest in Pennsylvania. Therefore, the availability of underclay and refractory clay along with glacial clay lenses in New York should be similar to those in Pennsylvania.

North Carolina. The state of North Carolina contains no known salt deposits. Saline groundwater occurs at varying depths along the state's coastal plain and may provide areas of opportunity for evaporation of seawater for power generation utilization.

North Dakota. The western one third of North Dakota is underlain by large reserves of bedded salt at depth. The depth to the salt ranges from 3000 ft to over 12,000 ft. The area is fairly extensive as this is a major portion of the Williston Basin salt complex. In addition, in north-central North Dakota another formation of bedded salt exists and is the shallowest occurrence of salt in the state. The depth to the salt is about 3700 ft and is known as the Mission Canyon Salt.

In the northern portion of the Williston Basin within the state there are indications that KCl (potassium chloride) exists at depth ranging from thin deposits around 6300 ft to thicker deposits around 9000 ft and deeper.

Covering the same area as the bedded salts subsurface brines are available in fairly high concentrations. The brines range from 7000 ppm to those in excess of 300,000 ppm. These are naturally at shallower depths than the bedded salts.

North Dakota also has $NaSO_4$ lakes in the northwestern part of the state. The four major lakes are Miller, Grenora 2, Stanley A, and White, which is the largest.

Within the state there are adequate reserves of clay of various types. The clays are located fairly close to the surface with 20 to 40 ft of overburden in many areas. The geographical extent of the clay covers many of the bedded salt formations of the Williston Basin.

Ohio. Approximately 9800 mi^2 of the state of Ohio is underlain with rock salt of Silurian age in the eastern and northeastern portions of Ohio. Salt

may be obtained at a relative shallow depth of 1275 to 1350 ft in Sheffield and Avon Townships in Lorain County. At Barberton the top of the salt lies at a depth of about 2800 ft and from this point the salt gradually becomes deeper until it lies at a depth of 6700 ft below the surface in Marshall County, West Virginia. This rock salt deposit is part of the Salina Basin salt that extends from Michigan to New York. The salt is being mined through solution mining techniques.

Underlying even more of the state are natural brine units. These brines can be tapped. Brine is also associated with oil and gas recovery within the state, much of which is available for salt ponding.

Clay exists in sufficient quantities to be used as a liner for power generation ponds.

The terrain in western Ohio may be more suitable for a pond, but it is heavily cultivated and is away from the bedded salts. Eastern Ohio is more rolling, but is underlain by the bedded salt.

Oklahoma. Western Oklahoma is underlain by large reserves of salt that are part of the Permian Basin. The depth to the top of the rock salt beds range from about 30 ft below the surface down to 945 ft. The thickness varies, but is considerable. In addition to the rock salt, groundwater that comes in contact with the salt deposits form a natural brine. This brine covers a considerable portion of western Oklahoma. The drainage basins collect much of the brine which in turn contaminates much of the fresh water supply and rivers. The Cimarron River, for example, carries an estimated 2600 tons of salt per day past the gauging stations. Several salt springs in western Oklahoma contribute about 6000 tons of salt per day to the water supply. In western Oklahoma several salt flats exist. The two largest are Great Salt Plain and Big Salt Plain, 15,000 and 4000 acres, respectively. The other salt flats range in size from 400 to 2000 acres. The salt plains are flat, barren areas of sand, silt, and clay adjacent to major rivers. Brines flow from the bedrock into the base of these loose deposits and permeate them. The accessibility of the salt, brine, and land makes western Oklahoma a good area for potential power generation ponds. Below is a list of playa salt derived from salt springs:

(1) Great Salt Plain
(2) Big Salt Plain
(3) Little Salt Plain
(4) Blaine County Salt Plain
(5) Beham County Salt Plain
(6) Salton Gulch
(7) Robinsons Gulch
(8) Kiser Gulch
(9) Jackson County Salt Plain

Oregon. The state of Oregon does not have any known rock salt deposits, however, several salt springs and lakes exist. These can be found in the counties of Columbia, Douglas, Jackson, Josephine, Multnomah, Polk, and Yamhill.

In Lake County there are salt lakes of significant size. These are Sumner Lake and Lake Albert. Alkali Lake is another salt lake that is in Lake County. Near Vale and Ontario, Oregon, is the most extensive brine spring in Oregon. Some thought may be given to Goose Lake at Lakeview, Oregon. The coastal region of Oregon may be too mountainous to facilitate a power generation pond whereas southeastern Oregon may be better.

Pennsylvania. Rock salt underlies about half the state and is part of the Salina Basin. The salt is found at depth ranging from about 2200 ft in Erie County to over 9000 ft in the southwestern and west central parts of the state. Much of the bedded salt is found in the northwestern half of the state. Within the same geographical area of bedded salt subsurface brines can be found. Most of the naturally occurring brines are associated with oil and gas recovery. These brines tend to be a sweet water contaminate due to the porosity of the soil.

Rock exists in the state that are formed from clay minerals. This form of clay is termed underclay and is usually crushed and reconstituted to form plastic clay. A clay base shale-like rock also covers part of the state and is the base for refractory clays and is impermeable. Both forms of clay can be used for lining after proper preparation. Plastic clay exists in lenses in northwestern Pennsylvania and some lenses may be large enough for pond lining. These lenses are associated with glacial deposits and are usually found as a result of other activity.

Rhode Island. The state of Rhode Island contains no known salt deposits. The coastal areas of the state may present some opportunity for evaporation of seawater.

South Carolina. The state of South Carolina contains no known salt deposits. The coastal areas of the state may provide areas for evaporation of seawater.

South Dakota. The state of South Dakota contains bedded salts of the Williston Basin in northwestern South Dakota in Butte and Harding Counties. The salts are part of the Pine Salt member of the Williston Basin. The depths range from about 4000 to 5400 ft or 2300 to 2600 ft below sea level, with an approximate thickness of 300 ft. The salts are obtainable through solution mining techniques.

Bentonitic clays and clay lenses associated with glacial drift are found in the vicinity of the salt deposits. Bentonitic clays of Wyoming are adjacent to South Dakota's salt deposits.

Tennessee. The state of Tennessee contains no known salt deposits. Some saline groundwater at around 4000 ft in depth is reported in Maury County.

Texas. Texas has vast reserves of salt located in two different geologic provinces. These reserves consist of bedded rock salt, salt domes, and brines. These reserves are independent of any solar evaporation of salt from the Gulf of Mexico. The two provinces are the Gulf Coast Basin and the Permian basin.

The Gulf Coast Basin is comprised of two related salt complexes: salt domes and bedded salt. The Gulf Coast Basin covers about one third of the state from the coast to a line roughly from Texarkana to Dallas to Eagle Pass. The first complex are domes that vary in depth to their tops and in areal extent. These domes usually have oil and gas production associated with them. About 27 domes lie between 1000 ft of the surface. Another 23 lie between 1000 and 2000 ft beneath the surface. The remainder of the known Texas domes lie below 2000 ft with most between 2000 and 10,000 ft, although

some lie deeper. The second complex is bedded salts that lie at depth in a geographical extent that includes the domes underlying about one third of the state. Two major salt beds make up this complex. They are the Haynesville Salt and the Louann Salt. The Haynesville Salt varies in thickness from 60 to 890 ft; in Hunt County it is about 60 ft thick, while in Freestone County it is about 130 ft thick, whereas, in northeastern Texas it is about 890 ft thick. Depths to the Haynesville Salt are not known for all locations, but in eastern Texas it lies at depths from 3000 to 10,000 ft. The Louann Salt is the other major salt bed and is much more massive than the Haynesville Salt and covers a much larger geographical area. The Louann Salt is the main salt formation of the Gulf Coast Basin and is sometimes referred to as the Mother Salt. The Louann is considered the source of the salt domes in not only Texas, but also in Louisiana, Mississippi, and Alabama. The Louann Salt lies at depths below 10,000 ft.

The Permian Basin is the other province in which bedded salt is found at depth. This portion of the Permian Basin extends throughout most of the Texas Panhandle and down through West Texas from New Mexico and Oklahoma. The Permian Basin is divided into other basins and into formations. The Salado and Castile salt formations and the Delaware Basin lie in both West Texas and eastern New Mexico. The Salado Formation underlies about 25,000 mi^2. The depth to the Salado salt formation ranges from 400 ft in the southwestern part of the area to more than 2500 ft in the northern part. In the Delaware Basin the depth to salt ranges from 700 to 800 ft on the west side and south side to about 1500 ft on the northwest side and 1000 to 2000 ft on the shelf area of the basin. More than 1700 ft of salt are found on the north and east edges of the Delaware Basin and about 1000 ft of salt in a small area on the shelf area adjacent to the Delaware Basin. The oldest salt formation of the Permian basin is the Castile. It is confined within the Delaware Basin. The thickness varies from 200 to 700 ft, although usually less than 250 ft. The depth to the salt of the Castile may range from 3000 ft or below, in that it lies beneath the Salado Salt. The remaining portion of the Permian Basin Salt north of West Texas in the Panhandle takes on the characteristics of those portions found in western Oklahoma and eastern New Mexico. The thickness ranges up to 500 ft or thicker at depths from 390 to 1200 ft. The Panhandle salt beds are part of the same sequences that are found in eastern New Mexico and western Oklahoma.

Associated with the Permian Basin and the Gulf Coast Basin are brines. Much of these brines are associated with oil and gas recovery.

In addition to the reserves of dome and bedded salts there are many playa lakes in western Texas. These are used primarily as salt sources for cattle. One series of lakes is called the Lakes of Guadalupe and is located about 90 mi east of El Paso. The salt in the lakes varies in thickness from 1 to 4 in.

Clay is found in eastern Texas and is abundant. A major clay formation runs northeast-southwest on a general line running from Laredo to Texarkana. The clay resources of Texas are adequate for large scale pond lining operations.

Utah. Within the state of Utah there are four major areas of salt. First, the Paradox Basin in eastern Utah contains salt at depth. The bedded salt

deposits occupy portions of Emery, Garfield, Grand, San Juan, and Wayne Counties. The salt ranges in thickness from zero along the outer boundaries to in excess of 3000 ft. The salt, however, is fairly deep, between 5000 and 6000 ft. Portions of the deposit are within 1500 to 2000 ft of the surface. In the folded portions of the Basin the salt may be as close as 500 ft below the surface. This basin extends into western Colorado.

Second, the Great Salt Lake, Great Salt Lake Desert, and the Bonneville Salt Flats all of which are the remnants of the vast Lake Bonneville and are obvious potential sites.

The third area is the Sevier Valley in central Utah. Near Redmond, Utah, in the Sevier Valley about 200 ft of salt is exposed in the abandoned pit of the Great Western Salt Company. The salt contains a considerable amount of red clay and salt intermixed. Over 200 ft of similarly bedded salt occurs north of Redmond. This would also be a good potential site. Another deposit north of Redmond stretches 5 mi and is 800 ft thick. There is no estimate of the reserves for the Sevier Valley area.

The fourth area consists of what may be the best area for large solar pond power generation. This is the Sevier Basin with the Sevier Lake which covers several townships. The lake basin including the dry lake has been suggested by the State of Utah as a possible site.

Vermont. The state of Vermont contains no known salt deposits.

Virginia. The state of Virginia contains small deposits of bedded salts in Washington and Smyth Counties in western Virginia. Associated with these deposits are salt water seeps and brines. The Chesapeake Bay-Atlantic coastal areas may present opportunities for evaporation of seawater.

Washington. The state of Washington contains no known salt deposits. Puget Sound exhibits salt water intrusion. In Grant County it is reported that Soap Lake may contain around 241,000 tons of dissolved salt. The lake is reported to also be dilute. The Pacific coastal areas and Puget Sound areas may present some opportunity for evaporation of seawater.

West Virginia. The state of West Virginia contains bedded salts of the Salina Basin that underlies, roughly, the northern third of the state. The minimum depth to the salts is about 5000 ft, with thicknesses perhaps from 100 to 120 ft. Brines are at shallower depths and underlie, roughly, the northwestern half of the state. Both the bedded salts and brines are obtainable through solution mining techniques.

Wisconsin. The state of Wisconsin contains no known salt deposits.

Wyoming. The state of Wyoming contains four areas of bedded salts. These are the Green River Basin, the Powder River Basin, the Idaho-Utah-Wyoming border area, and the Lusk Embayment.

In the Green River Basin halite is intermixed with trona in a geographical extent about 108 mi^2. The depth ranges from around 600 to 2250 ft.

Along the tri-border area of Idaho-Utah-Wyoming bedded halite is reported on all sides of the border region. Lower Crow Creek and Tygee Valley report rock salt and brines exist. In Lower Crow Creek rock salt is found 6 ft below the surface and at least 20 ft thick. In Tygee valley about 125 ft below the surface six rock salt beds totalling 96 ft thick are reported. On the Utah side of the border region rock salt 700 ft thick is reported 6000 ft below the surface.

The Powder River Basin in the northeastern quadrant of the state is reported to contain bedded salts at depths ranging from about 6600 ft to over 15,500 ft with varying thicknesses of around 90 to 180 ft in individual beds about 33 ft thick.

The Lusk Embayment is thought to extend northwestward from Coloradô and Nebraska. (Information regarding Wyoming's portion is sketchy and there is some doubt as to the existence of Lusk Embayment salt in Wyoming.)

Brines are associated with oil and gas production within the state. Non-mixing layers of natural brines of differing salinities are known.

In the northeastern quadrant of the state, bentonite mines exist with some adjacent to the South Dakota salts of the Williston basin.

Commonwealth of Puerto Rico. Information regarding the availability of salts in the Commonwealth of Puerto Rico was not obtainable. The coastal areas of Puerto Rico may present opportunities for the evaporation of seawater for power generation pond applications.

2.2 METEOROLOGICAL AND HYDROGEOLOGICAL CONDITIONS

2.2.1 Ambient Temperature

Annual average temperature in the United States is charted in Figure 2-8. Curves superimposed on the map are isopleths of average temperature. (For monthly average temperatures charted on similar maps, see Appendix G, Figures G-1 to G-12.)

Average air temperature in the central and eastern United States varies principally with the latitude. Air temperatures in the western states are influenced by the local geography of seacoast, mountains and desert. Monthly average temperature varies in an annual cycle, with the minimum in January when average temperature ranges from less than 5°F in the North to over 60°F in the South. The maximum of the temperature cycle occurs in July in the North, with temperatures above 70°F, and in August in the South, above 85°F. The net annual swing of the temperature cycle (based on monthly average temperatures) ranges from 25°F in the South to 65°F in the North.

Hawaii and Puerto Rico experience monthly average temperatures in the 70 to 80°F range each month, with annual temperature swings on the order of 10°F.

The overall performance of ponds used for heating will be closely related to average temperature, as higher ambient temperature will result in higher output, if other factors are kept constant.

To maintain a constant pond output year-round, the annual temperature swing should be small. However, the annual temperature cycle may be used to advantage in optimizing the design of certain pond systems, such as systems where summer or fall heating is required. A pond's long-term storage design option (i.e., greater depth) may make up for the deficiencies associated with annual temperature swing.

In contrast, the performance of ponds used for generating electric power, where the efficiency is a function of the temperature difference between the surface and storage zones, is not sensitive to the annual average temperature. However, the annual ambient temperature cycle, coupled with the annual insolation cycle, can cause wide swings in power plant efficiency during the year, an important factor to consider in the design of a base-load electric power plant.

The potential freezing of the top layer of a pond depends on the ambient temperature. The salinity of the surface layer would lower its freezing temperature below that of fresh water, but the reduced upper layer turbulence and lack of natural convection in the pond as compared with an ordinary fresh water pond would enhance freezing. Because energy is being drawn out of a solar pond, the pond will, on the average, have a slightly lower surface temperature than a convecting pond. However, this effect would be smaller in a pond whose surface is used as a heat sink, such as one used to generate electric power.

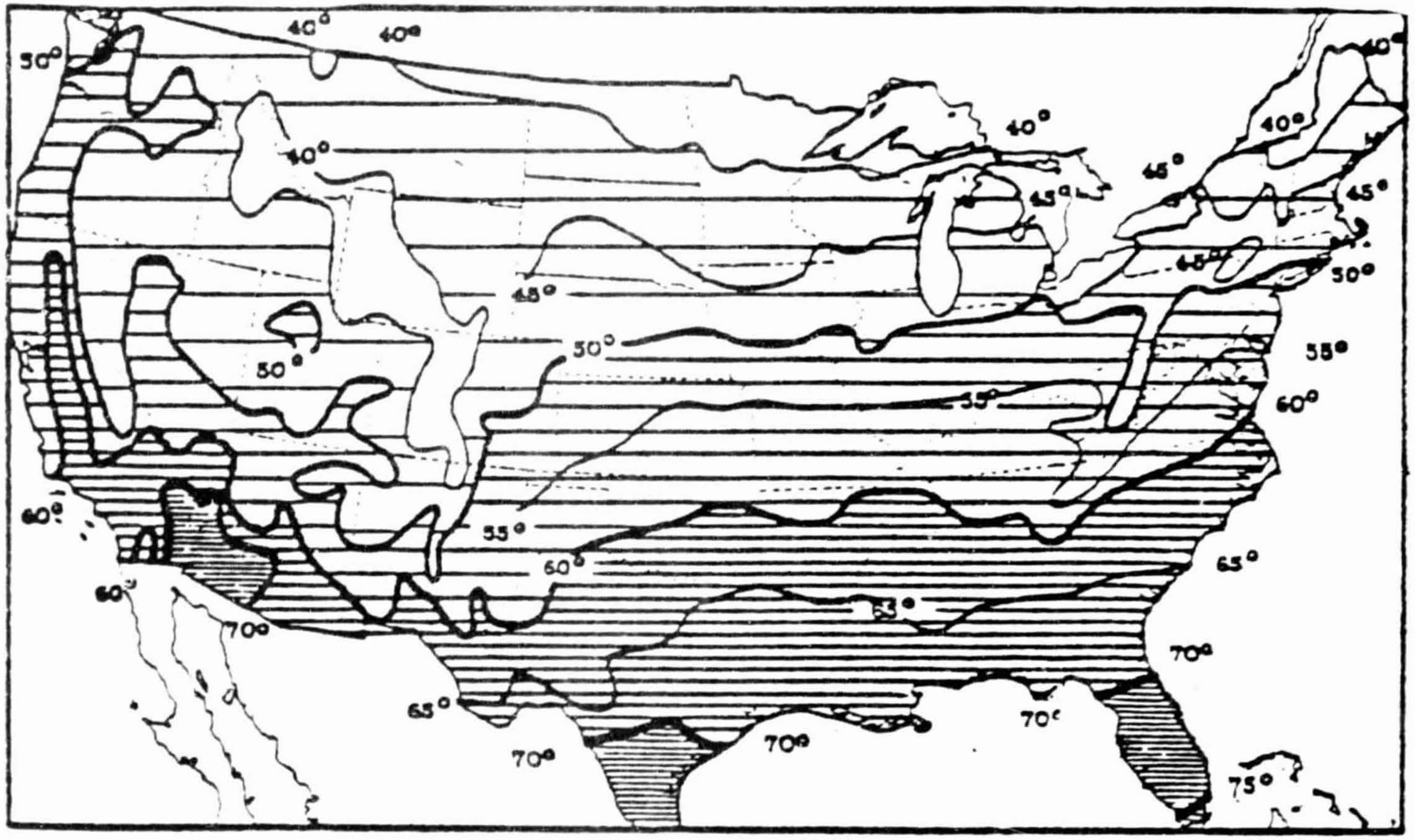

Figure 2-8. Annual Average Temperature in the Conterminous United States, °F (Source: Visher, 1954)

2.2.2 Evaporation

The total annual evaporation from lakes and other open bodies of water is shown in Figure 2-9 (see also Appendix G, Section 2). The evaporation has been determined by mass balance from measurements of rainfall, inflow, outflow, and estimates of ground seepage.

Evaporation is highest in the southwest desert region, as high as 86 in./yr, decreasing toward a minimum of 20 in./yr in the northeast. The evaporation isopleths tend to follow the same pattern as those for insolation (Fig. 2-1 and Appendix B, Fig. B-2 through B-4). The major fraction of evaporation occurs in the period May to October (Appendix G, Fig. G-15), the mean of which is loosely correlated to the latitude, except along the Pacific coast, and ranges from below 66% in the South to above 80% in the North.

The evaporation is closely related to the amount of makeup water required for a pond. Low evaporation is a desirable climatic condition, but is correlated with low insolation. Methods to suppress evaporation from a solar pond have been investigated.

A minor effect of lower evaporation, whether natural or artificial, is that the surface temperature will be slightly higher. The slightly higher surface temperature would benefit ponds used for heating, but would reduce electric power plant cycle efficiency unless the storage layer temperature could also be raised.

2.2.3 Precipitation

The distribution of average annual total precipitation in the United States is shown in Figures 2-10 through 2-12. West of 100° longitude, annual precipitation ranges from 5 to 20 in., except for the desert areas (less than 5 in.) and the northern Pacific coast (up to 100 in.). Moving eastward, there is a rapid increase in precipitation. East of 95° longitude, the total is 35 to 40 in./yr in the North and 50 to 55 in./yr in the South. (For a state-by-state annual average total precipitation see Appendix G, Fig. G-16.)

Lines of equal precipitation do not tend to run parallel to lines of equal evaporation except in the area of Kansas-Oklahoma-Texas. As a result, the average net water loss from a pond (i.e., evaporation minus precipitation) will vary throughout the country. Throughout the East and South, there will be a net annual surplus in the pond during a typical year, although the major evaporation season will not necessarily coincide with the major rainy season. In many climates, it may be necessary to use a variable surface rinsing rate, determined in part by the rainfall itself, to maintain a pond.

It is conceivable that a very severe hailstorm may disrupt an operating solar pond (Appendix G, Fig. G-17). In a typical hailstorm, the pond surface layer will absorb the impacts of the hailstones, which will float until they melt. Extremely large hailstones might penetrate into the gradient layer and cause some degree of disruption to the gradient.

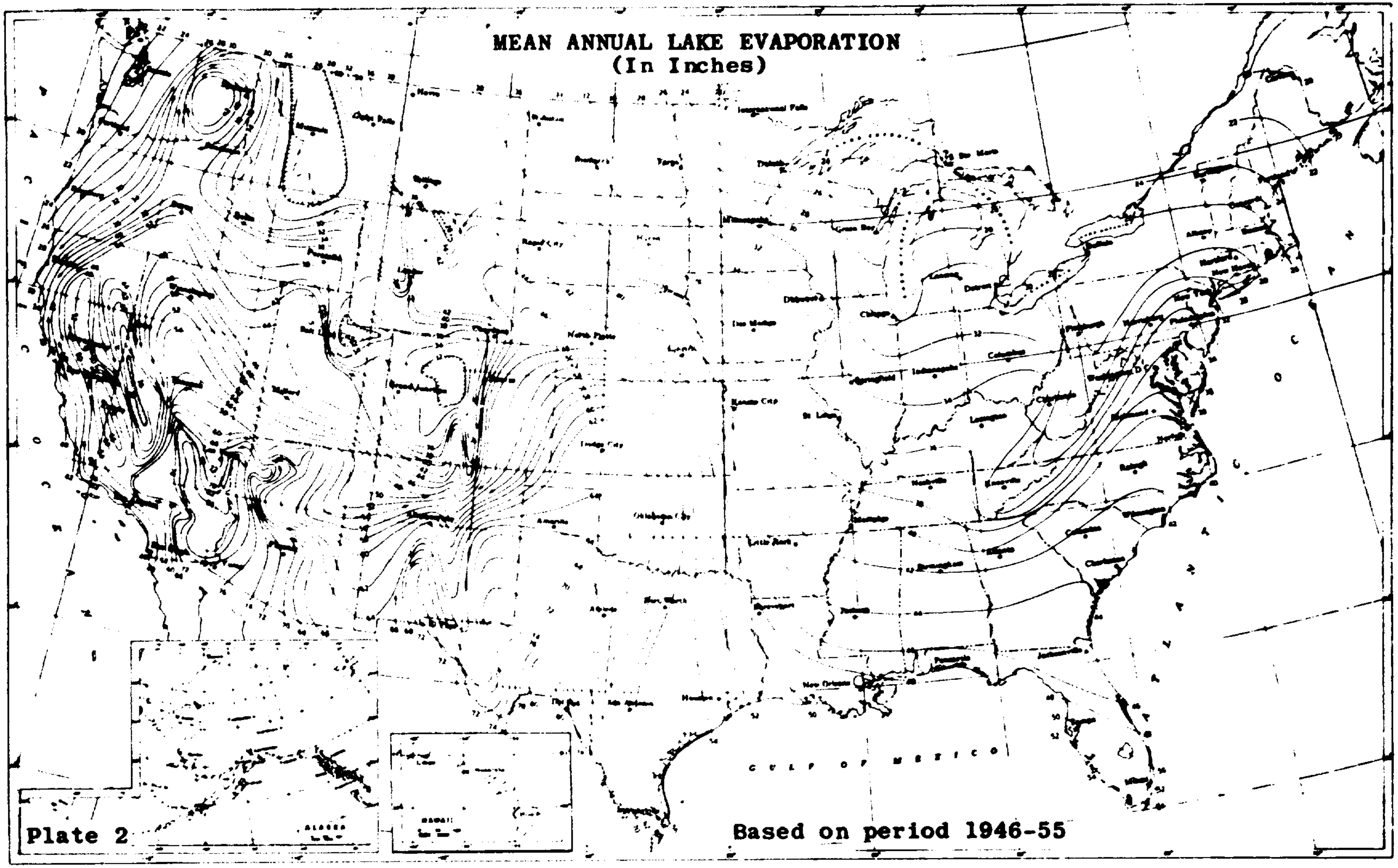

Figure 2-9. Total Annual Evaporation From Lakes and Other Open Bodies of Water in the Conterminous United States, in. (Source: U.S. Dept. of Commerce, 1979)

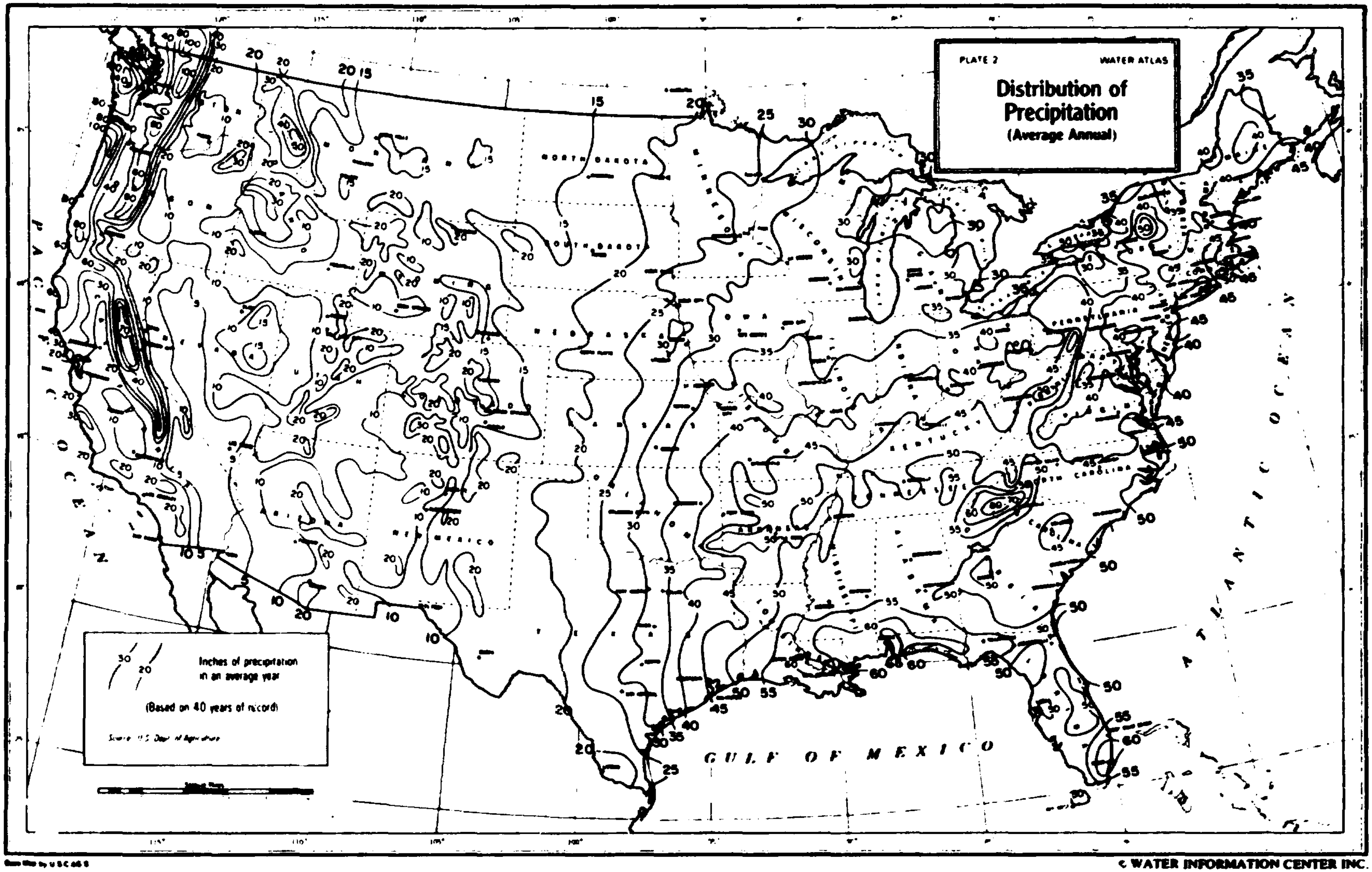

Figure 2-10. Average Annual Total Precipitation Distribution in the Conterminous United States, in. (Source: Geraghty, et al, 1973)

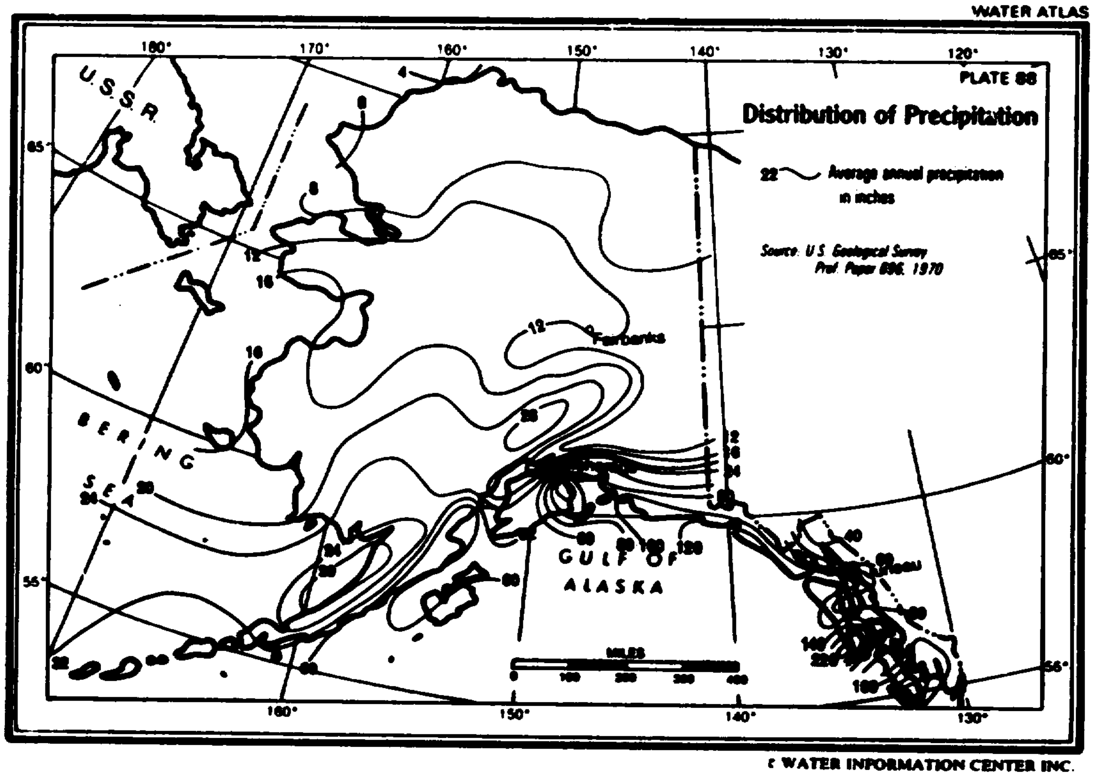

Figure 2-11. Average Annual Total Precipitation: Alaska, in.
(Source: Geraghty, et al, 1973)

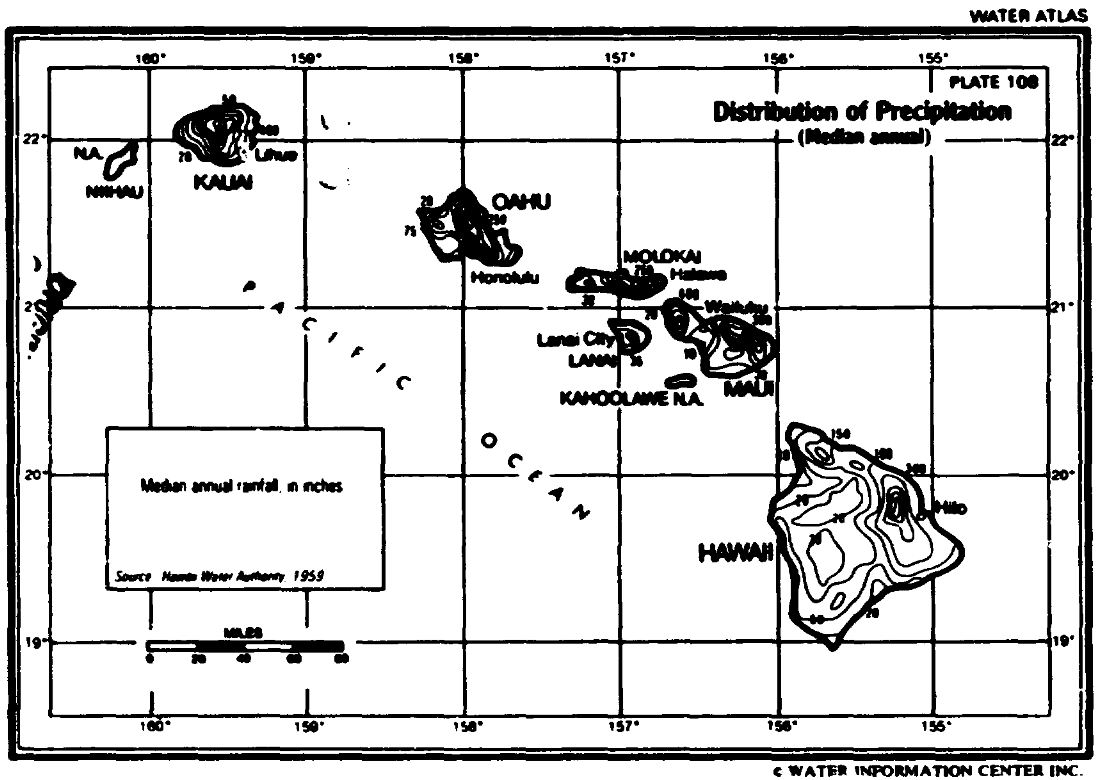

Figure 2-12. Average Annual Total Precipitation Distribution: Hawaii, in.
(Source: Geraghty, et al, 1973)

Snowfall on an unfrozen pond will be readily melted if in small quantities. However, a large quantity of snowfall on a frozen pond will substantially reduce the transmittance of solar radiation into a pond (Appendix G, Fig. G-18).

2.2.4 Topography

Major topographical features of the United States are shown in Figure 2-13. Approximately half the area of the lower 48 states and Alaska is composed of broad, relatively flat plains. Other regions are alternating mountains and valleys or basins. No region of the United States is so continuously mountainous as to preclude the consideration of pond construction in the region solely on the basis of topography. Topography is a site-dependent factor, to be considered in any specific pond design.

2.2.5 Soil

Soil conditions pertinent to solar ponds are site-specific. It is preferable to have clay or impermeable strata below the pond to ensure that the brine will not be lost or pollute the surrounding aquifers. Clay for pond liners is believed to be locally available throughout most parts of the United States. Where sandy or silty soils characterize a pond site, environmental protection will require installation of plastic liners or equivalant ground sealers. Soil conditions are an important factor to consider in siting a pond.

2.2.6 Groundwater

Groundwater as a source of water supply to solar ponds is discussed in Section 2.1.3. It is preferable that the groundwater table be sufficiently far below the pond bottom so that flowing groundwater will not constantly convect heat away from a pond. Where flowing groundwater is within 10 ft of pond bottom, artificial barriers may be constructed around the pond to divert groundwater flow so that a stagnant groundwater region is created directly beneath the pond. The depth of groundwater is a site-specific factor that is an essential part of the siting consideration.

2.2.7 Wind and Hurricane

The highest wind speeds recorded at these locations throughout the United States are shown in Table 2-15 as the "fastest mile." The number of years of data represented is shown in the YRS column. Over 40% of the locations have experienced no winds over 70 mph. Many locations, such as Evansville, Indiana, have had extremely high winds in only one month, probably indicating that such high winds are rare occurrences in those locations. Other locations, such as New York City and Colorado Springs, Colorado, show very high winds in several months, indicating that high winds are a more frequent occurrence. About half the winds over 100 mph were measured at locations along the Gulf of Mexico and the Atlantic coast, and were presumably hurricanes. The annual-average wind speed and direction at specific locations

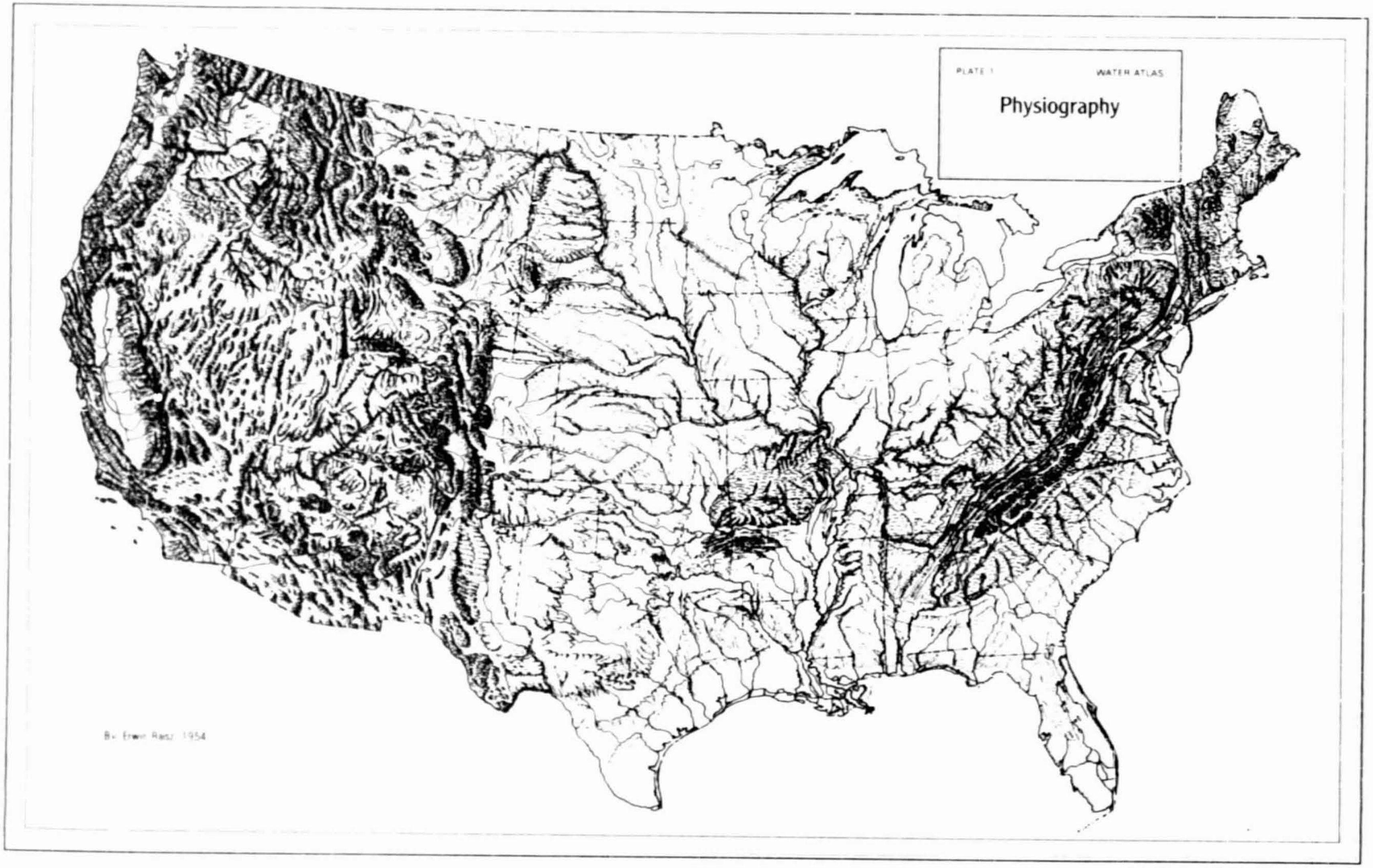

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Figure 2-13. Major Topographical Features of the Conterminous United States (Source: Geraghty, et al, 1973)

Table 2-15. Highest Wind Speeds (mph) Recorded at Locations Throughout the United States (Source: U.S. Department of Commerce, 1979[b])

FASTEST MILE AND DIRECTION OF WIND

STATE & STATION	YRS	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
ALA. BIRMINGHAM	30	49 SW	59 SE	65 SW	56 SW	65 NW	56 SW	57 SW	50 NW	50 SE	43 W	32 N	45 SE	65 SW
MOBILE	28	45 SW	44 E	48 SE	36 SE	44 E	47 E	61 E	69 NE	75 N	87 E	47 E	42 E	87 E
MONTGOMERY	30	47 SW	47 W	60 SW	54 SE	59 W	51 NW	51 W	43 SW	40 NE	40 W	46 S	46 SW	60
ALASKA ANCHORAGE	10	60 NE	62 S	49 N	[illegible] S	31 S	33 S	32 S	45 S	49 SE	39 S	66 NE	56 SW	66 NE
BARROW	30	56 E	58 W	48	52	43 SW	39 W	56	47 E	56 W	51	63 W	70 W	70 W
FAIRBANKS	11	41 SW	57 W	40 SW	35 SW	42 SE	40 SW	36 SW	34 W	49 SW	50 SW	50 SW	45 WSW	60 SW
JUNEAU	15	[illegible] SE	[illegible] SE	[illegible] SE	[illegible] SE	[illegible] SE	[illegible] SE	[illegible] SE	[illegible] SE	[illegible] SE	[illegible] SE	[illegible] SE	[illegible] SE	[illegible] SE
ST. PAULS ISLAND	14	70 SE	69 NE	59 SW	69 NE	46 NW	38 NE	25 SE	52 SW	51 NE	60 S	114 NE	84 SE	114 NE
NOME	21	75 W	74 W	72 S	58 E	46 NE	37 S	36 SE	45 E	52 SE	73 SW	73 SW	54 NE	75
SHEMYA	16	[illegible] WSW	81 SW	79 SSE	73 SSE	62 WSW	55 SW	50 WSW	55 S	71 SW	79 WSW	89 W	139 SW	139 SW
ARIZ. PHOENIX	24	41 WNW	49 SSE	50 WSW	45 WSW	39 SSE	46 NE	71 N	60 SSW	75 SW	48 SSW	45 SSW	48 W	75 SW
PRESCOTT	17	47 SW	65 SW	65 SW	65 SW	60 SE	54 SW	54 NW	44 SW	56 SW	61 S	72 SW	52 W	72 SW
TUCSON	14	[illegible] E	[illegible] E	41 SE	[illegible] SE	[illegible] SW	[illegible] SE	[illegible] S	[illegible] E	[illegible] SE	[illegible] SE	[illegible] E	[illegible] W	[illegible] E
YUMA	51	36 W	42 NW	56 NW	47 NW	38 W	41 E	52 NE	54 S	42 SE	39 NW	47 S	47 W	56 NW
ARK. FORT SMITH	16	42 SW	56 W	41 SW	42 NW	57 NW	58 N	37 W	44 NE	72 NE	54 W	56 W	41 SW	58 S
LITTLE ROCK	20	44 S	46 WSW	56 SE	65 NW	61 NW	60 NE	56 NW	54 NW	50 NW	58 SSW	49 SW	42 SE	65 NW
CALIF. BAKERSFIELD	18	47 ESE	58 ESE	35 WNW	40 NNW	40 WNW	37 NW	28 NW	30 WNW	32 NNW	32 E	45 WNW	40 SSE	60 NNW
BLUE CANYON	4	66 NNW	64 SSW	67 ENE	42 ENE	37 SW	49 ENE	32 E	30 ENE	49 E	70 NE	47 ENE	51 ENE	70 NE
BURBANK	5	40 NE	38 NNW	32 NW	39 NNW	29 S	25 NE	19 S	20 SE	19 ESE	30 NNW	38 NNW	45 NE	45 NE
EUREKA	51	54 S	49 SW	48 SW	49 S	40 SW	39 NW	35 N	34 N	44 S	43 SW	43 S	56 S	56 S
FRESNO	13	32 SE	38 W	31 SE	36 NW	38 N	34 W	25 NE	31 S	29 SW	40 NE	27 SE	43 NW	43 NW
LOS ANGELES	21	49 N	40 NW	40 NW	40 NW	39 NW	32 N	21 W	24 E	27 NW	42 N	42 S	44 SE	49 N
RED BLUFF	17	59 SE	61 SE	63 SE	50 SE	40 SE	38 NW	34 SE	30 SW	43 W	56 SE	47 SE	60 SE	63 SE
SACRAMENTO	65	60 SE	58 SE	66 S	45 SSW	40 SE	47 SW	36 SW	38 SW	37 NW	68 SE	70 SE	70 SE	70 SE
SANDBERG	7	[illegible] NW	[illegible] NW	[illegible] NNW	[illegible] NW	[illegible] NNW	[illegible] NW	[illegible] NNW	[illegible] S	[illegible] NNW	[illegible] NW	[illegible] NNW	[illegible] E	[illegible] E
SAN DIEGO	38	39 SW	35 SW	46 SW	37 S	27 SW	25 W	18 SW	22 SW	25 W	31 N	51 SE	34 S	51 SE
SAN FRANCISCO	24	60 SW	62 SW	52 SW	48 W	36 W	48 W	50 W	45 WSW	48 S	51 SW	55 SSW	53 S	62 SW
COLO. COLO. SPRINGS	7	74 NW	74 SW	64 WNW	59 W	68 SSW	60 SSW	70 SE	54 W	74 SW	63 NW	60 W	69 WNW	[illegible] SSW
DENVER	69	51 SW	50 W	53 NW	56 NW	65 W	56 SE	57 SE	47 N	50 NW	47 S	58 NE	51 NW	65 W
GRAND JUNCTION	64	54 W	50 NW	65 S	59 W	61 SW	66 S	56 SW	56 SW	41 S	61 SW	56 W	66 NW	66 S
PUEBLO	21	80 W	56 N	68 N	72 N	66 NW	63 N	61 W	58 SE	56 S	65 N	61 S	57 S	80 W
CONN. BRIDGEPORT	5	60 NW	47 WNW	45 WNW	45 SSW	32 W	60 WSW	40 WSW	32 S	30 SSE	38 ESE	62 E	35 S	62 E
HARTFORD	45	51 SW	50 W	57 SE	47 NE	41 NW	52 S	42 SW	56 SE	63 S	57 S	70 E	54 NW	70 E
NEW HAVEN	18	39 S	36 SE	42 E	40 SE	31 SW	32 SW	33 NW	38 NE	41 S	44 E	57 E	41 SW	57 E
D. C. WASHINGTON	13	56 SW	57 SW	60 E	56 S	68 S	57 SW	54 E	49 SE	56 SE	78 SE	60 E	62 SW	78 SE
WASHINGTON U	67	47 SW	47 SW	58 SW	50 SW	47 SW	47 SW	54 SE	49 NW	62 SE	54 NW	47 SW	40 NW	62 SE
FLA. APALACHICOLA	29	44 E	40 SE	54 E	51 SE	47 SE	47 NE	43 S	38 NE	47 E	56 NW	47 SE	42 SE	[illegible] E
DAYTONA BEACH	12	38 W	40 S	40 SW	46 S	32 S	35 WSW	40 NNW	50 ESE	45 ESE	39 SE	29 ENE	40 NNW	50 SE
FORT MYERS	10	39 SSE	40 SSE	40 SW	40 SSE	30 SW	41 SSE	45 S	47 WSW	*90 E	*58 ENE	30 SW	30 SSW	*90 E
JACKSONVILLE	30	51 SW	76 W	66 SW	54 NW	57 SE	58 SW	53 W	56 SW	51 SE	72 E	68 S	54 SW	[illegible] W,SE
KEY WEST	50	71 N	63 WNW	52 W	50 W	51 E	49 S	32 ESE	56 S	122 NW	66 SE	76 NW	49 NW	122 SW
FLA. (CON'T) MIAMI	51	50 SW	68 SE	53 S	70 S	48 SW	48 NE	53 SE	62 SW	132 E	122 S	94 SE	52 S	132 E
PENSACOLA	22	35 NW	42 SE	49 NW	41 NW	40 NW	33 SW	35 SE	57 W	91 SE	32 NW	35 SW	36 SE	91 SE
TAMPA	51	47 SE	59 SW	56 SW	50 SW	56 NE	56 NE	62 SE	57 S	84 SE	68 NE	40 NW	51 NW	84 SE
GA. ATLANTA	50	54 NW	59 W	[illegible] SW	[illegible] SE	[illegible] NW	[illegible] NE	[illegible] SE	[illegible] NW	[illegible] N	67 NW	[illegible] NE	63 W	70 NE
AUGUSTA	40	46 -	43 -	37 -	41 -	46 SSW	43 -	48 -	46 -	44 -	37 -	40 W	39 -	48 -
MACON	62	47 SE	60 NE	60 S	57 SE	65 SE	56 NW	59 SW	70 S	43 SE	36 N	54 SW	36 W	70 S
SAVANNAH	51	57 SW	62 SW	[illegible] S	[illegible] SW	[illegible] W	[illegible] E	[illegible] W	[illegible] N	[illegible] NW	[illegible]	57 SE	51 SW	90 N
HAWAII HONOLULU	27	67 SW	63 W	59 SE	40 NE	35 E	39 E	34 E	32 NE	35 NE	41 NE	65 NE	59 NE	67 SW
LIHUE	11	36 SE	34 E	38 S	29 NE	49 NE	30 NE	31 NE	73 NE	30 NE	32 E	43 S	58 NE	73 NE
IDAHO BOISE	22	50 SE	58 W	52 W	50 W	[illegible] W	50 SW	61 W	50 SE	57 SE	58 SE	57 NW	56 NW	61 W
IDAHO FALLS (46W)	11	39 WSW	36 SW	51 WSW	39 WSW	41 SW	36 SW	35 WSW	33 SW	38 WSW	44 WSW	40 SW	43 SW	51 WSW
POCATELLO	49	61 SE	54 W	72 W	61 S	61 W	50 W	47 S	56 SW	57 W	54 W	67 W	56 SE	72
ILL. CAIRO	71	56 SW	56 SW	59 SW	59 SW	62 S	52 N	59 S	56 S	57 NW	40 NW	50 SW	43 S	62 S
CHICAGO	40	58 NE	87 NE	76 NE	69 SW	69 SW	62 NW	69 SW	62 SW	69 SW	62 SW	76 SE	66 SW	87 NE
MOLINE	33	56 SW	58 NW	66 SW	73 SW	68 SW	77 SW	65 W	61 SW	66 NW	56 SW	60 W	61 SW	77 SW
PEORIA	50	54 S	52 W	58 S	60 SW	61 SW	66 N	75 NW	65 W	60 W	60 SW	58 SW	58 SW	75 NW
SPRINGFIELD	83	65 SW	63 SE	66 SW	56 W	58 W	75 SW	59 NW	58 W	52 SW	44 S	68 SW	66 SW	75 SW
IND. EVANSVILLE	50	51 SW	76 W	62 SW	61 SW	56 SW	113 S	60 W	60 SW	51 W	41 SW	62 SW	54 S	113 S
FORT WAYNE	50	58 SW	52 W	65 S	60 W	58 SW	65 SE	61 NW	47 S	58 W	61 NW	57 SW	52 SW	65 SE
INDIANAPOLIS	90	90 W	65 SW	68 NW	60 W	68 W	111 NW	72 NE	68 W	62 W	56 NW	59 SW	53 W	111 NW
SOUTH BEND	11	42 S	47 NNW	47 SW	42 SW	40 WNW	50 W	45 NNW	63 NW	35 WSW	38 WSW	65 S	43 SE	63 NW
IOWA BURLINGTON	20	69 W	66 NW	58 SW	72 W	66 SW	70 NW	58 NW	73 N	65 W	63 W	67 W	72 SW	73 N
DES MOINES	30	66 NW	56 W	70 NW	63 NW	71 SW	76 NW	66 NW	60 SSE	55 NW	56 W	72 W	61 SW	76 NW
DUBUQUE	76	31 NW	30 NW	34 SW	32 NW	32 SE	47 SW	44 NW	36 SE	35 SE	30 NW	34 NW	34 SE	47 SW
SIOUX CITY	50	59 NW	62 NW	[illegible] NW	68 W	[illegible] W	91 W	61 N	91 SW	66 S	70 W	59 NW	56 NW	91 W,SW
KANS. CONCORDIA	50	37 N	44 NW	54 NW	67 NW	60 NW	65 W	50 NW	47 NE	34 SW	41 NW	47 N	40 NW	65 W
DODGE CITY	18	56 NW	72 NW	74 NW	70 NW	71 NW	73 S	78 SW	72 SW	66 N	63 NW	58 NW	57 NW	78 SW
TOPEKA	50	43 SW	50 N	60 SW	63 SE	67 SE	57 NW	91 N	57 N	57 N	63 NE	49 S	61 S	91 N
WICHITA	73	51 NW	56 NW	62 NW	68 NW	70 SW	73 NE	100 N	59 NW	59 NW	52 NE	72 S	52 S	100 N
KY. LEXINGTON	45	52 S	47 SW	53 SW	50 SW	50 SW	47 SW	49 NW	56 S	53 W	40 NW	52 NW	47 S	56 S
LOUISVILLE	49	53 S	42 W	62 SW	66 SW	60 NW	65 NW	57 SW	63 NW	57 NW	50 NW	60 SE	61 SW	66 SW
LA. LAKE CHARLES	21	46 SSE	42 SSE	55 NW	46 SSE	50 WNW	69 SE	45 S	43 SSE	50 NE	42 WNW	46 WNW	50 S	69 SE
NEW ORLEANS	47	41 SE	44 S	62 NW	35 SE	43 SE	40 NE	37 NW	41 SE	98 SE	31 SE	28 SE	31 SW	98 SE
SHREVEPORT	62	47 NW	45 NW	57 S	52 N	47 NW	50 E	46 NW	52 W	58 E	47 NW	50 SW	52 NW	58 E
MAINE CARIBOU	8	76 NW	52 W	63 W	46 NW	52 WNW	50 WNW	66 N	45 WNW	65 W	48 NW	48 W	55 WNW	76 NW
PORTLAND	62	50 S	58 SE	76 SE	57 S	64 NW	68 NW	51 S	69 E	62 SE	47 SE	76 SE	62 SE	76 SE
MD. BALTIMORE	39	52 NW	65 NW	66 W	65 W	57 NE	61 N	61 NE	60 SW	54 SW	58 NW	57 S	58 NW	66 W
MASS. BLUE HILL	53	72 SW	74 WNW	69 SW	57 W	59 S	76 WNW	67 NW	93 SE	121 S	63 SE	70 S	82 WNW	121 S
BOSTON	43	66 SW	58 NW	73 E	63 NE	55 W	46 NW	52 NW	52 SE	87 S	63 NE	80 SE	73 W	87 S
NANTUCKET	75	69 NE	71 NE	91 E	61 NE	52 NE	68 NE	62 NE	79 SW	73 SE	69 E	70 NW	62 NE	91 E
WORCESTER	4	60 WSW	76 NW	76 WNW	54 NE	48 W	39 WSW	43 NW	34 W	34 SW	43 WSW	54 SSW	51 SW	76 WNW
MICH. ALPENA	45	56 E	50 NW	56 E	52 W	47 NW	50 NW	49 S	52 S	49 SE	50 NW	61 NW	49 NW	61 SW
MICH.(CON'T) DETROIT	[illegible]	57 SW	49 W	68 SW	56 S	61 NW	56 SW	77 NW	50 NW	52 SW	56 S	66 W	59 NW	77 NW
ESCANABA	30	52 NE	56 S	68 N	47 S	57 NW	50 SE	49 S	43 NW	47 NW	52 NE	56 S	47 NW	68 N
FLINT	19	76 SW	65 SSW	63 SE	67 SSW	81 SW	64 S	44 NNW	60 WSW	46 NNW	52 WSW	56 WSW	46 SW	81 SW
GRAND RAPIDS	50	[illegible] SW	[illegible] SW	[illegible] SW	[illegible] SW	[illegible] SW	[illegible] S	[illegible] SW	[illegible] SW	[illegible] SW	[illegible] SW	[illegible] SW	[illegible] SW	[illegible] SW
LANSING	22	46 S	41 SW	38 SW	38 S	49 NW	38 NW	42 NW	29 NW	37 NW	44 SW	50 SW	33 W	50 SW
MARQUETTE	49	52	56 SW	57 SW	47 SE	91 S	59 SW	61 S	52 SW	45 S	66 SW	50 SW	57 S	91 S
S. STE. MARIE	71	[illegible] NW	72 NW	60 SE	72 SW	49 SE	74 W	58 W	58 SW	62 SW	62 W	[illegible] W	58 NW	72 SW
MINN. DULUTH	35	65 NW	67 E	75 NW	73 NE	61 W	59 NW	72 W	68 S	60 NW	61 S	68 E	72 NW	75 NE
INTERN'L FALLS	9	33 SW	35 N	42 NNW	53 SE	52 SSW	36	46 S	36 NNW	25 NW	29 SW	35 NW	32 W	52 SW
MINNEAPOLIS	50	47 NW	52 NW	56 SW	58 W	56 NW	63 NW	92 W	57 NW	50 NW	73 S	60 SW	52 W	92 W
MISS. JACKSON	14	56 NW	45 NW	68 S	49 S	56 NW	52 SE	54 S	51 NW	54 SE	39 NW	51 S	59 NW	68 S
MERIDIAN	55	42 -	41 -	47 -	44 -	40 -	40 -	40 -	36 -	32 -	32 -	31 -	38 -	47 -
VICKSBURG	50	38 NW	47 NW	40 NW	56 W	49 NW	38 SW	46 S	41 SE	47 S	35 SW	47 SW	49 SW	56 W
MO. COLUMBIA	50	56 NW	45 NW	56 SW	57 NW	58 SW	58 NW	61 NW	56 NW	63 NW	49 NW	49 NW	56 NW	63 NW
KANSAS	71	66 NW	49 NW	70 SW	61 W	68 SW	68 NW	70 NW	72 NW	50 NW	56 W	56 SW	57 SW	72 NW
ST. JOSEPH	48	[illegible] NW	46 W	64 S	61 NW	63 W	60 NW	52 W	57 NW	[illegible] SW	[illegible] NW	[illegible] NW	[illegible] S	[illegible] S
ST. LOUIS U	45	59 SW	57 SW	82 SW	61 SW	61 SW	60 SW	56 SW	60 SW	73 W	62 SW	65 SE	56 SW	82 SW
SPRINGFIELD	16	55 SW	59 S	65 SW	60 SW	66 W	57 N	56 NW	59 W	54 S	49 S	59 SE	55 W	66 W
MONT. BILLINGS	18	[illegible] W	68 NW	61 NW	72 NW	[illegible]	65 SE	73 N	[illegible] W	61 NW	[illegible] NW	[illegible] NW	[illegible] NW	73 N
GREAT FALLS	18	65 SW	72 W	73 W	70 W	65 SW	70 W	73 W	71 SW	73 SW	73 W	73 SW	82 SW	82 SW
HAVRE	40	52 SW	56 SW	47 SW	58 SW	58 SW	54 W	53	38 SW	70 SW	53	54 SW	47	70 SW
HELENA	50	73 SW	73 W	61 SW	52 W	62 S	59 SW	60 SW	[illegible] S	54 NW	62 W	59 SW	58 NW	73 W
MISSOULA	28	52 S	52 E	53 NE	51 NW	57 SW	51 S	72 SE	56 SW	41 W	51 SW	42 NW	56 W	72 SE
NEBR. LINCOLN U	50	49 NW	56 NW	63 NW	56 NW	60 W	66 NW	65 NW	62 NW	50 S	44 S	52 NW	54 NW	66 NW
NORTH PLATTE	50	57 N	68 N	72 N	63 NW	[illegible] S	72 N	[illegible] NW	[illegible] SW	[illegible] N	72 SW	[illegible] NW	[illegible] NW	72 N
OMAHA	49	60 NW	59 N	73 NW	65 NW	73 NW	72 N	109 N	66 N	51 N	59 SW	56 NW	52 NW	109 N
SCOTTSBLUFF	10	40 NW	60 WNW	48 W	46 NW	80 NW	80 WNW	52 WNW	41 NNW	46 NW	44 WNW	52 NW	47 NW	80 WNW
VALENTINE	50	[illegible] N	56 N	49 NW	55 N	[illegible] NW	[illegible] W	[illegible] SW	[illegible] NW	[illegible] S	[illegible] SE	[illegible] W	[illegible] N	[illegible] NW
NEV. ELY	18	66 SE	56 S	59 SE	59 S	74 S	63 SW	50 S	57 E	57 S	65 S	51 S	61 SE	74 S
RENO	56	66 SW	66 SE	68 S	66 SE	63 SW	64 S	63 W	57 S	68 S	66 S	59 SW	72 S	72 S
WINNEMUCCA	46	56 W	59 W	63 W	49 S	[illegible] S	53 W	56 W	51 W	57 W	54 NE	58 SW	[illegible] E	[illegible] E
N. H. CONCORD	50	43 NW	42 S	71 NE	52 NW	48 NW	38 SW	37 NW	56 E	41 SE	39 NW	72 NE	51 NE	72 NE
MT. WASHINGTON	29	170 W	144 SE	186 E	231 SE	164 W	136 NW	110	142 ENE	157 SE	161 W	160 SE	175 W	231 SE
N. J. ATLANTIC CITY	37	[illegible] E	77 SE	72 SE	[illegible] NE	[illegible] NE	57 NE	61 SW	[illegible] E	91 NE	72 NE	72 E	[illegible] NE	91 NE
NEWARK	10	46 WSW	50 WSW	55 WSW	52 WSW	40 W	55 ENE	45 S	46 E	43 NW	48 ENE	82 E	42 SSW	82 E
TRENTON	49	62 SE	60 W	60 NW	54 NE	56 E	57 NW	73 NE	67 N	56 NW	60 NW	64 E	56 W	73 NE
N.MEX. ALBUQUERQUE	30	[illegible] E	[illegible] SW	[illegible] NW	72 S	72 W	[illegible] SE	[illegible] E	[illegible] SE	[illegible] SE	[illegible] E	[illegible] NW	[illegible] SE	[illegible] SE
ROSWELL	57	67 NW	70 SW	66 SW	75 W	72 N	66 W	66 SW	72 W	54 NW	66 W	65 W	72 W	75 W
N. Y. ALBANY	50	57 W	71 SW	55 W	49 W	50 W	45 W	43 NW	38 S	48 S	45 NW	70 E	54 W	71 NW
BINGHAMTON	18	59 NW	[illegible] SW	61 NW	52 W	54 W	60 NW	[illegible] W	[illegible] S	42 NW	72 S	57 SE	[illegible] NW	72 S
BUFFALO	50	91 SW	73 SW	84 SW	73 W	63 SW	73 W	62 SW	68 W	68 SW	71 W	76 SW	85 SW	91 SW
NEW YORK CITY	46	76 SW	91 SW	91 SW	95 NW	74 W	74 W	95 NW	74 NW	99 N	113 SE	87 W	91 NW	113 SE

Table 2-15. Highest Wind Speeds (mph) Recorded at Locations Throughout the United States (Source: U.S. Department of Commerce, 1979[b])

ORIGINAL PAGE IS OF POOR QUALITY

FASTEST MILE AND DIRECTION OF WIND

STATE & STATION	YRS	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
FLA. (CONT'D) MIAMI	31	56	66	53	70	60	60	55	62	132	132	54	52	132
PENSACOLA	22	35	42	49	41	40	33	35	57	91	32	35	36	91
TAMPA	51	47	50	56	50	54	56	62	57	84	60	60	51	84
GA. ATLANTA	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	70
AUGUSTA	40	46	43	37	41	46	43	46	46	46	37	46	39	46
MACON	62	47	60	49	57	65	56	50	70	43	36	54	36	70
SAVANNAH	31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HAWAII HONOLULU	27	67	63	50	40	35	30	34	32	35	41	65	50	67
LIHUE	11	36	34	30	30	40	30	31	73	30	32	63	36	73
IDAHO BOISE	33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
IDAHO FALLS (400)	11	30	36	51	30	41	34	35	33	38	44	40	43	51
POCATELLO	49	63	54	72	61	61	50	47	58	57	54	47	56	72
ILL. CAIRO	71	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CHICAGO	64	56	87	76	69	69	62	69	62	60	62	76	66	87
MOLINE	33	56	58	66	73	60	77	65	61	66	56	60	61	77
PEORIA	34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SPRINGFIELD	63	65	63	66	56	56	75	50	50	52	66	60	64	75
IND. EVANSVILLE	50	51	76	42	41	54	113	60	60	51	41	63	54	113
FORT WAYNE	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
INDIANAPOLIS	90	90	65	80	60	60	111	72	60	62	56	50	53	111
SOUTH BEND	11	42	47	47	42	60	50	45	43	35	30	45	43	63
IOWA BURLINGTON	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DES MOINES	30	66	56	70	63	71	70	66	60	55	50	72	41	76
DUBUQUE	70	31	30	36	32	32	67	64	36	35	30	34	34	67
SIOUX CITY	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
KANS. CONCORDIA	50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DODGE CITY	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOPEKA	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
WICHITA	73	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100

Table 2-15. Highest Wind Speeds Recorded at Locations throughout the United States (cont'd.)

FASTEST MILE AND DIRECTION OF WIND (cont'd)

STATE & STATION	YRS	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
N.Y. (CON'T) ROCHESTER	51	73	66	65	58	63	61	56	59	59	65	59	57	73
		W	W	W	W	SW	SW	W	NE	SW	SW	E	W	W
SYRACUSE	50	56	61	59	57	49	59	52	49	47	63	59	69	69
		SW	W	SW	S	NW	NW	NW	NW	SW	SE	E	SW	SW
N. C. ASHEVILLE	50	52	43	44	47	49	49	40	34	43	44	40	42	52
		-	NW	SE	SE	-	-	-	-	-	NW	-	NE	-
CAPE HATTERAS	50	76	88	68	61	60	35	77	77	110	56	65	56	110
		SW	S	W	SSW	SW	NNE	NW	SE	W	SE	N	NW	W
CHARLOTTE	50	57	54	47	53	48	57	50	54	47	50	47	57	57
		SW	SW	W	NW	NW	NW	NW	N	NW	SW	NW	NE	SW,NNE
GREENSBORO	33	40	51	54	42	59	56	63	45	40	43	40	45	63
		NW	W	SW	W	SW	W	S	W	S	N	SW	SSW	S
RALEIGH	41	50	68	59	58	65	50	47	50	38	52	47	52	68
		SW	SW	SW	NW	SE	W	NW	NW	NE	W	SE	E	SW
WILMINGTON	49	57	66	56	56	50	54	42	72	88	82	42	47	88
		S	SW	SW	NE	NW	NW	NW	NE	S	SE	SW	SW	S
WINSTON-SALEM	8	40	46	45	43	48	29	48	46	42	42	42	43	48
		SSE	WSW	W	W	NW	NE	SSW	NE	E	NE	NW	NE	SSW
N. DAK. BISMARCK	87	70	54	65	62	68	68	72	72	88	81	67	61	72
		NW	NW	NW	W	NW	NW	W	S	NW	W	NW	NW	W
DEVILS LAKE	57	41	54	54	47	52	50	56	47	46	47	57	42	57
		SW	N	N	S	NW	W	NW	NW	NW	N	N	NW	N
FARGO	41	57	56	56	65	72	115	60	71	88	57	66	58	115
		W	W	S	S	NW	NW	SE	NW	N	NW	N	N	NW
WILLISTON	34	38	37	43	41	45	56	60	46	42	40	53	47	60
		W	SE	W	NW	W	E	W	W	N	W	NW	NW	W
OHIO CINCINNATI	40	49	49	49	47	36	40	43	38	38	35	47	41	49
		SW	SW	SW	SW	W	W	SW	W	SW	SW	SW	SW	SW
CLEVELAND	31	71	65	74	65	78	68	66	61	56	68	67	59	78
		W	SW	W	NW	SW	NW	W	W	S	W	SW	W	SW
COLUMBUS	59	63	58	68	76	56	62	84	78	51	60	61	58	84
		NW	SW	SW	W	NW	NW	NW	NW	SW	S	N	W	NW
DAYTON	47	60	72	75	72	60	78	74	70	65	56	68	70	78
		NW	SW	W	SW	SW	NW	NW	W	W	SW	SW	W	NW
SANDUSKY	84	56	64	65	75	48	77	69	63	52	54	68	56	77
		SW	SE	SW	SW	SW	NW	N	NE	NW	N	SW	NW	NW
TOLEDO	50	66	69	87	72	58	56	76	76	62	57	76	69	87
		SW	SW	SW	SW	SW	W	SW	W	S	SW	SW	SW	SW
OKLA. OKLA. CITY	47	63	61	61	75	72	87	73	56	54	65	66	56	87
		W	W	S	NW	SE	NNW	NW	S	NW	S	S	NW	NNW
TULSA	19	55	50	51	70	75	65	56	56	48	45	56	56	75
		SW	N	SW	NW	SW	NW	N	N	E	NW	SW	SW	SW
OREG. PORTLAND	50	54	61	50	60	42	40	31	29	38	50	56	57	61
		S	SW	S	S	SW	SW	S	SW	SW	SW	SW	S	SW
ROSEBURG	9	34	38	27	29	22	22	25	25	25	33	31	31	38
		SW	SW	SW	SW	S	N	NW	N	N	S	SW	S	SW
PA. ERIE	42	56	57	60	56	51	47	51	58	56	51	60	53	60
		SE	W	SW	W	SW	SW	W	SE	SW	SE	SE	SW	SW,SE
HARRISBURG	50	47	60	68	58	46	46	47	45	40	50	58	61	68
		W	-	W	SW	-	-	NW	-	-	E	SE	NW	W
PHILADELPHIA	50	62	59	61	54	73	73	88	67	49	73	60	47	88
		N	NW	S	S	NW	NW	N	E	NE	S	SW	NW	N
PITTSBURGH	79	67	58	72	60	73	58	64	57	54	56	49	60	73
		NW	NW	W	W	NW	NW	SW	NW	NW	NW	NW	NW	NW
READING	49	84	78	65	80	95	62	68	56	58	72	69	64	95
		SE	NW	NW	E	NW	NW	W	E	NW	SE	E	S	NW
SCRANTON	17	42	60	42	47	40	43	56	50	42	50	45	49	60
		W	W	W	NW	NW	W	NW	NE	SW	SE	S	SW	W
R. I. BLOCK ISLAND	70	69	68	90	72	72	72	51	82	91	65	90	77	91
		NW	SE	E	NE	NE	NE	N	N	SE	E	NE	NW	SE
PROVIDENCE	49	70	63	69	65	58	60	58	49	95	90	80	85	95
		NW	SW	NW	NW	N	NW	NW	NW	SW	W	NW	W	SW
S. C. CHARLESTON	47	61	52	72	65	68	54	60	73	76	56	49	73	76
		-	NW	-	E	-	NW	-	-	-	-	-	NE	-
COLUMBIA	41	54	47	54	47	47	41	51	49	35	38	43	44	54
		SW	W	SW	SW	SW	N	SW	S	W	NE	SW	W	SW
GREENVILLE	18	73	56	63	66	65	52	60	70	47	79	52	50	79
		NE	NE	NW	NW	SW	N	N	SE	NE	N	SW	SW	N
S. DAK. HURON	29	57	56	68	73	70	65	77	70	64	72	73	56	77
		NW	NW	NW	SE	NW	SE	NW	S	NW	W	NW	NW	NW
RAPID CITY	50	73	75	72	72	67	72	70	72	73	72	59	65	75
		NW	NW	NW	NW	NW	SW	SW	SE	NW	NW	NW	NW	NW
TENN. CHATTANOOGA	83	58	63	82	57	63	67	48	62	57	35	45	48	82
		SW	W	W	W	NW	NW	NW	W	SW	NW	S	SW	W
KNOXVILLE	50	60	61	61	71	59	65	73	50	56	42	43	52	73
		SW	SW	SW	SW	SW	W	SW	S	W	SW	SW	SW	SW
MEMPHIS	50	58	51	54	51	57	51	54	41	51	47	43	56	57
		-	-	W	-	-	-	-	-	-	W	-	-	-
NASHVILLE	50	56	57	70	61	57	73	59	49	47	51	58	47	73

STATE & STATION	YRS	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	YEAR
		SW	-	NW	W	-	NW	-	-	-	-	-	W	NW
TEXAS ABILENE	49	52	60	71	61	73	109	63	51	55	49	50	56	109
		SW	S	S	S	N	SW	NE	NE	SW	S	N	N	NW
AMARILLO	70	62	70	72	74	84	65	66	65	68	68	56	62	84
		NE	NW	W	SW	SW	W	SW	E	NE	S	NW	NE	SW
AUSTIN	35	44	57	48	44	53	56	43	45	43	52	48	49	57
		W	N	NW	W	NW	W	S	NE	SW	S	NW	NW	N
BROWNSVILLE	39	51	56	47	52	57	52	41	57	106	47	42	50	106
		S	NW	S	SE	SE	E	SE	NW	NW	NE	NW	W	NW
CORPUS CHRISTI	75	58	50	54	54	69	55	56	100	110	47	62	47	110
		SE	SE	S	S	NE	SE	S	E	NE	N	NE	NW	NE
DALLAS	48	68	61	55	58	65	65	77	56	48	61	58	67	77
		SW	SW	W	S	S	W	N	NE	W	NW	W	S	N
EL PASO	83	61	69	70	66	70	68	65	63	58	58	57	66	70
		SW	W	SE	SW	NW	N	N	N	SW	W	W	W	NW
FORT WORTH	38	61	61	59	53	68	57	56	49	49	56	53	53	68
		SW	W	W	NW	W	NW	NW	N	N	W	NW	N	W
GALVESTON	86	53	80	50	58	80	62	68	91	87	68	54	50	91
		S	N	SE	S	W	SE	NW	E	NE	SE	N	NW	E
HOUSTON	52	50	53	84	63	60	54	73	80	66	70	46	49	84
		NW	SE	NW	NE	SE	SE	NW	SE	E	E	NW	SE	NW
LAREDO	11	45	75	43	42	40	61	55	40	46	45	37	34	61
		WNW	NNW	NE	NW	ESE	NE	ESE	ESE	NE	E	NE	SE	NE
LUBBOCK	12	53	58	69	58	70	63	64	46	45	65	59	50	70
		W	WSW	NNW	WSW	E	NE	WSW	SSE	S	WSW	WSW	WSW	S
MIDLAND	7	41	67	48	38	52	58	29	30	40	32	32	37	67
		NNW	WSW	WSW	SW	SSW	NNE	N	NE	N	NNE	N	SSE	WSW
PORT ARTHUR	24	68	56	57	56	57	72	65	91	73	70	56	69	91
		SW	SW	E	NW	SW	NW	SE	NE	SE	SE	SW	S	NE
SAN ANGELO	10	44	48	48	69	58	57	40	37	44	60	66	40	[illegible]
		W	WSW	NW	WNW	NNW	NNE	SSE	NNE	E	WNW	WNW	[illegible]	WNW
SAN ANTONIO	50	56	56	63	61	73	59	54	74	49	57	51	51	74
		NW	N	W	W	NW	E	SE	NE	NE	NW	W	NW	NE
VICTORIA	11	55	56	57	58	60	50	52	72	57	53	62	54	72
		NNW	NW	W	NW	NW	NW	ENE	NE	SSE	NW	NW	N	NE
WACO	18	45	46	58	52	56	64	49	48	48	54	50	65	65
		NW	NW	NNW	W	N	W	SW	WNW	NW	N	NW	NW	W
WICHITA FALLS	16	49	68	59	64	62	92	50	55	56	60	70	64	92
		NW	WSW	W	W	W	W	S	SSW	WNW	WNW	WNW	WNW	W
UTAH SALT LAKE CITY	50	52	56	71	56	57	54	53	58	61	67	63	54	71
		SE	SE	NE	NE	NW	N	N	NW	N	NW	NW	S	NW
VT. BURLINGTON	55	62	57	66	63	49	50	42	54	56	70	72	57	72
		S	S	S	S	S	SW	S	N	S	SE	SE	S	SE
VA. LYNCHBURG	50	57	48	48	62	56	47	47	46	47	62	46	46	62
		SW	SW	NW	W	S	N	N	SE	SW	NE	SW	NW	W
NORFOLK	50	62	62	63	62	70	80	63	70	75	78	53	62	80
		SW	SE	N	N	N	N	SE	NE	NE	S	NW	S	N
RICHMOND	50	62	51	51	67	56	53	56	50	45	68	67	68	68
		SW	NW	W	NE	SW	NW	NW	SE	SE	SE	SW	SW	SE
WASH. SEATTLE	28	63	64	60	65	45	54	38	35	55	63	57	60	65
		SW	S	SW	S	SW	SW	SW	SW	SW	S	SW	SW	S
SPOKANE	49	56	54	56	43	49	47	46	38	38	56	54	56	56
		SW	SW	W	W	W	SW	S	SW	SW	SW	SW	SW	W,SW
STAMPEDE PASS	9	94	91	78	61	61	56	42	33	56	81	82	84	[illegible]
		W	SW	SW	S	W	W	W	E	W	W	SW	W	W
TATOOSH ISLAND	59	87	84	91	73	66	70	53	59	68	73	94	85	94
		S	SE	E	SW	S	S	S	SW	NE	S	S	S	S
WALLA WALLA	46	42	47	62	41	32	37	36	29	51	54	67	47	67
		SW	W	W	NE	W	S	W	W	W	SE	SW	W	SW
YAKIMA	19	35	31	34	31	30	30	29	25	35	29	29	32	35
		NW	NW	SW	W	SW	W	NW	NW	SW	SW	NW	S	SW
W.VA. PARKERSBURG	73	45	45	47	47	43	49	62	37	61	38	66	35	66
		SW	NW	SE	SW	NW	NW	NW	N	NW	NW	NW	W	NW
WIS. GREEN BAY	49	61	66	68	57	109	73	70	56	66	66	67	61	109
		W	W	W	NE	SW	SW	NE	SW	W	SW	W	SW	SW
LA CROSSE	10	35	36	40	56	58	60	38	48	38	38	[illegible]	[illegible]	[illegible]
		NNW	WNW	NNW	SSE	E	NNW	N	W	SSW	WNW	S	NNW	NNW
MADISON	50	68	57	70	73	77	59	72	47	52	73	56	65	77
		E	W	SW	SW	SW	W	NW	W	W	SW	SE	SW	SW
MILWAUKEE	50	62	58	73	66	72	66	59	56	62	60	72	62	73
		W	NE	SW	SE	SW	N	W	N	S	S	W	SW	SW
WYO. CHEYENNE	50	75	69	73	67	69	63	57	48	54	81	[illegible]	71	[illegible]
		NW	NW	W	NW	NW	NW	W	NW	W	W	W	W	NW
LANDER	50	65	77	62	72	56	61	57	56	70	70	75	72	77
		SW	SW	SW	SW	SW	SW	W	SW	W	SW	N	SW	SW
SHERIDAN	50	73	70	65	68	71	66	73	72	66	66	84	63	84
		NW	W	SW	NW	NW	SW	W	NW	NW	NW	SW	NW	SW
P. R. SAN JUAN	60	46	43	41	35	45	40	62	80	149	43	40	[illegible]	149
		NE	W	W	W	N	NE	E	NE	NE	N	NE	E	NE

Direction indicates the direction from which wind was blowing at time of fastest mile.

Prevailing means most frequently observed. Arrows fly with wind.

Charts and tabulations based on "Normals, Means, and Extremes" tables in U.S. Weather Bureau publication, Local Climatological Data. Use with caution because of the effects of local topography, particularly in mountainous terrain.

C-2

in the conterminous United States are indicated in Figures 2-14. (For monthly averages, see Appendix G, Fig. G-19 to G-30). Weather station wind speeds are typically measured 30 ft abov ground. Average speeds are all far below the fastest mile speeds.

Wind is a significant factor in the performance of solar ponds. A major wind disturbance to the surface may damage the salinity gradient. As with other structures, local winds must be accounted for in the planning and design phases. Techniques for maintaining pond integrity under windy conditions have been investigated. Floating wave suppression networks have been demonstrated to maintain the pond strata in winds up to 70 mph.

A second-order effect of wind is the increased cooling of the pond surface in windy conditions. As wind speed increases, the surface temperature approaches the wet bulb temperature due to increased evaporation and convective heat transfer.

The distribution of hurricanes along the Gulf coast is diagrammed in Figure 2-15, a summary of 59 years of data. Each lateral segment shown in the figure is approximately 110 mi wide at the coastline. Except for south Texas, a hurricane has passed through each segment on the average every 2 to 3 years. Areas of extreme hurricane winds and significant property damage are usually more localized than the 110-mi-wide segments.

Local adaptation to avoid damage from high winds is shown in Figure 2-16, taken from the 1979 Uniform Building Code. Buildings in the western United States must withstand a 20 lb/ft^2 wind force at the 30-ft level. In the central states, the requirement is increased to 30 lb/ft^2, and requirements up to 50 lb/ft^2 are in force along the Gulf and Atlantic coasts, areas of maximum hurricane damage.

2.2.8 Seismic Activity

The estimated risk of seismic activity in the United States is mapped in Figures 2-17 to 2-19. Parts of the Deep South and Texas, noted for their extremely stable geological features, are considered to offer no risk of seismic damage. The risk increases to a maximum in parts of California, Nevada, and Alaska, where seismic activity is commonplace. Even in the highest risk region, major earth movement and/or substantial property damage at any given locality is an extremely rare occurrence (Appendix G, Fig. G-31).

Pond design and siting must take into account the risk of seismic activity, however remote, in order to protect nearby people, property, water supplies, and the ponds themselves.

2.2.9 Humidity

Annual average relative humidity is shown in Figure 2-20, with isopleths of percent relative humidity superimposed on the maps. (For monthly average, see Appendix G, Fig. G-32 through 43.) Annual average humidity in eastern and east-central United States range from 70 to 80%, and in

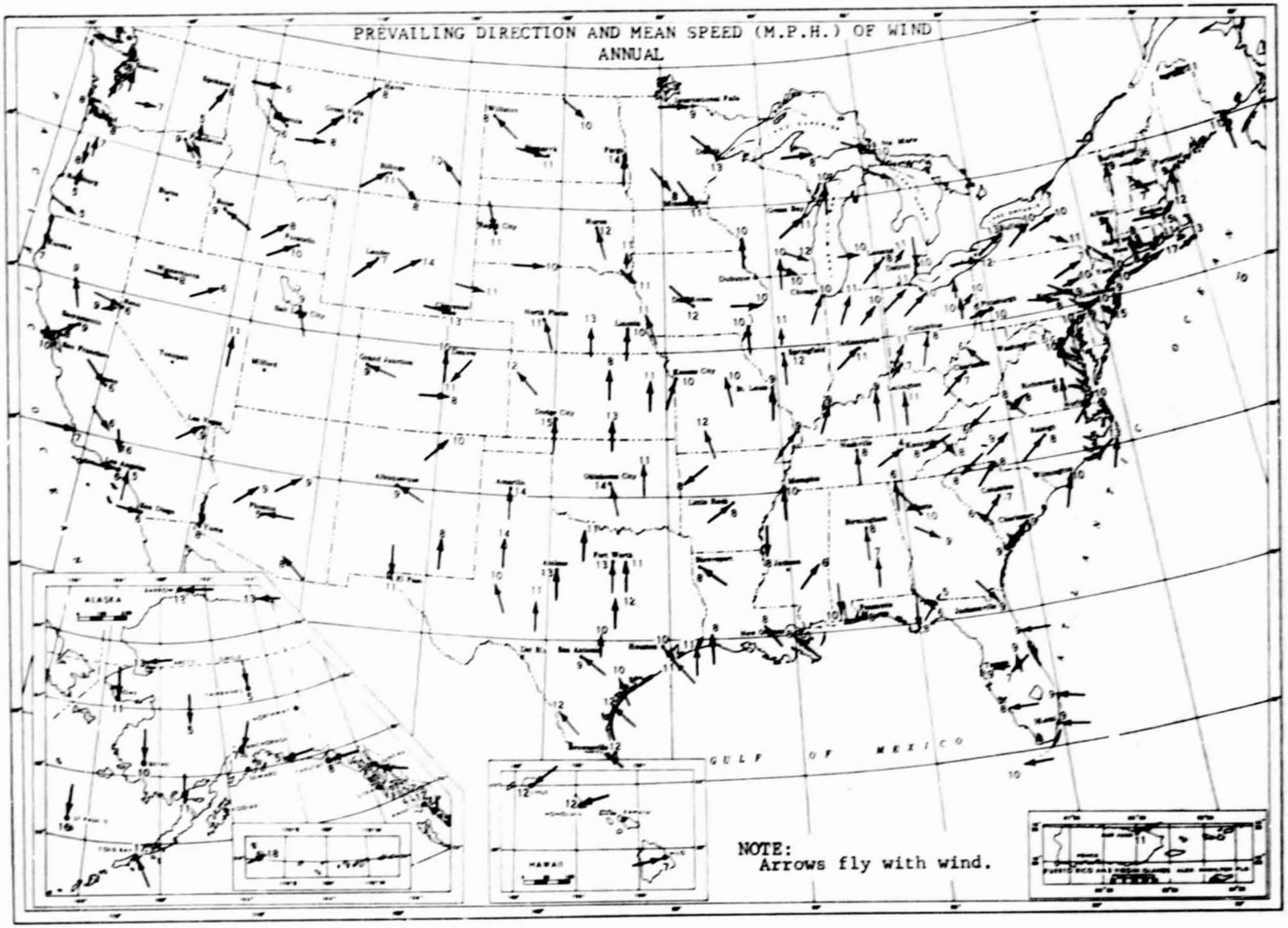
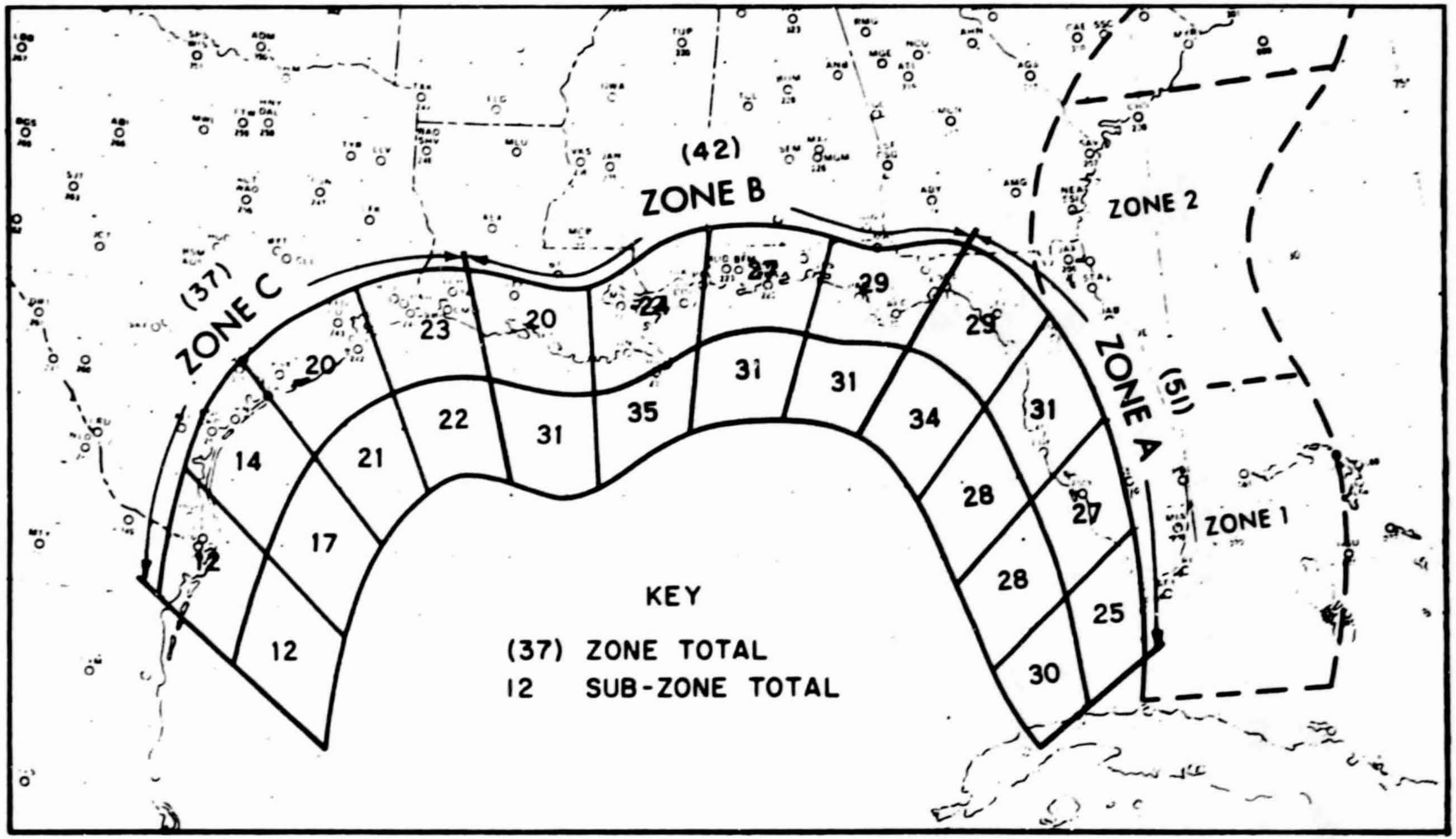
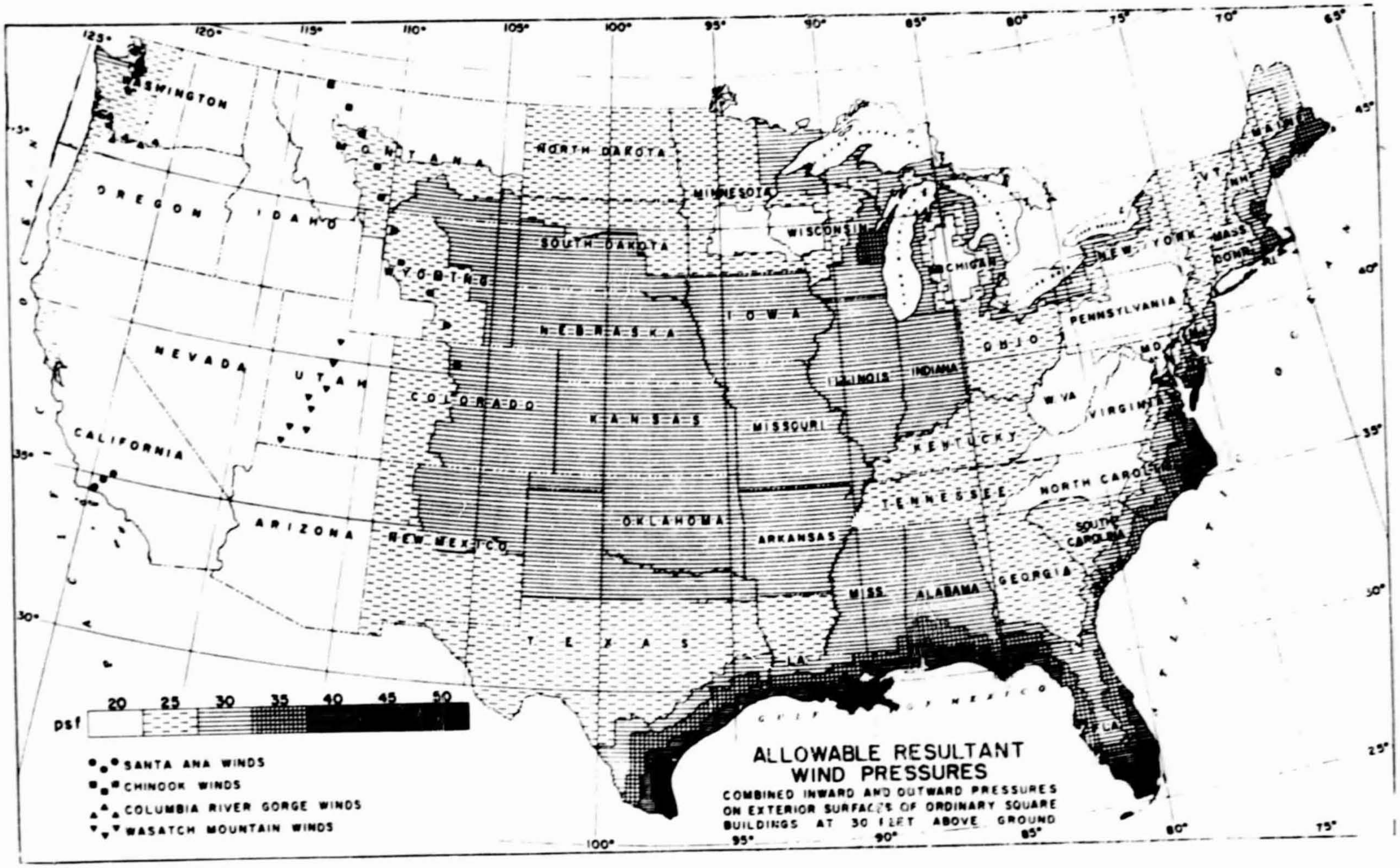


Figure 2-14. Average Annual Wind Speed (mph) and Direction in the United States
(Source: U.S. Department of Commerce, 1979)



Numbers indicate the number of hurricanes passing through each indicated sector during the period 1900 to 1956.

Figure 2-15. Distribution of Hurricanes Along the Gulf Coast (Source: Carr, 1967)



Shading indicates minimum wind pressure requirements for buildings. Darker shading means higher pressure.

Figure 2-16. Local Adaptation to Avoid Damage From High Winds (Source: 1979 Uniform Building Code)

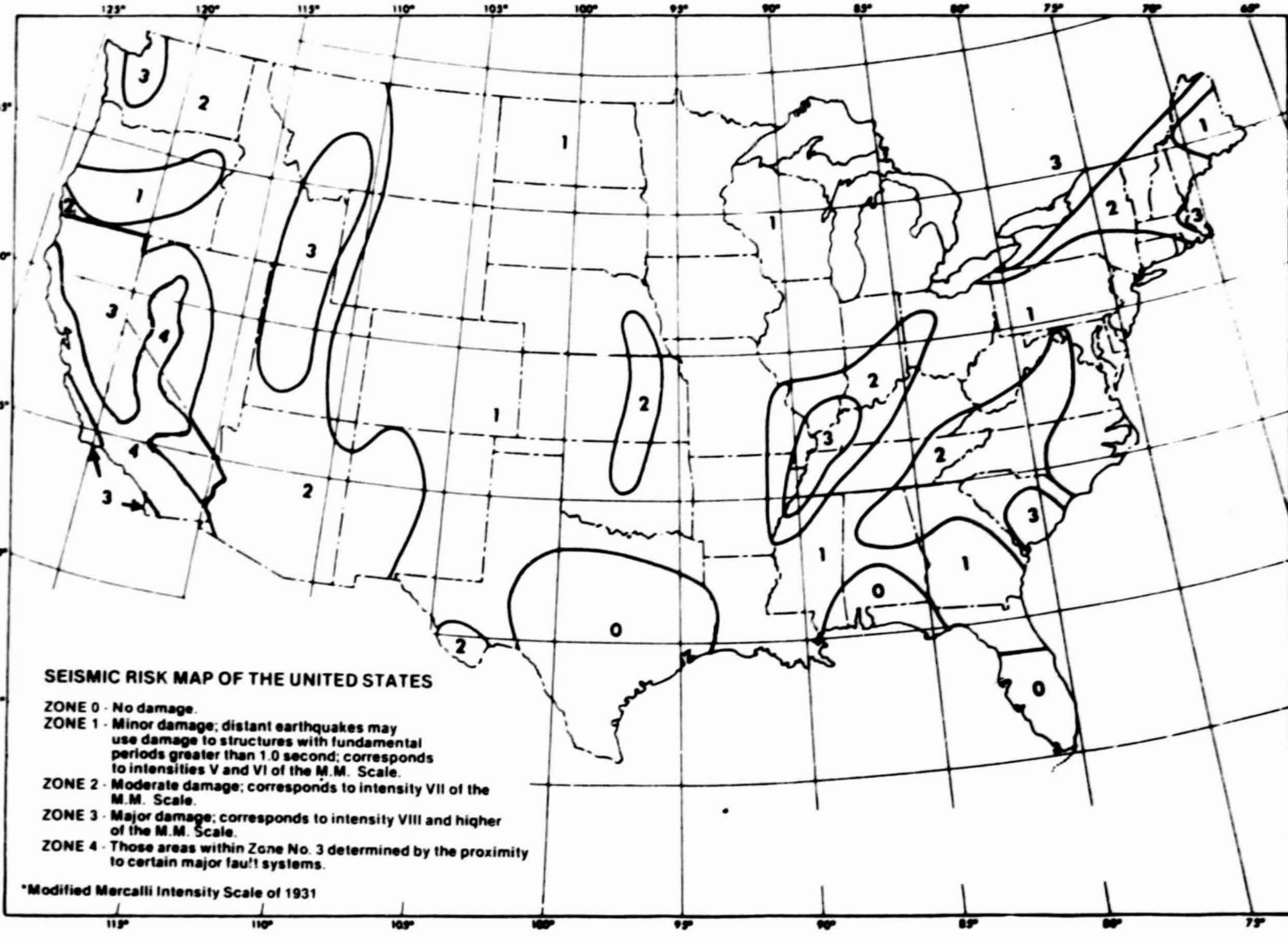


Figure 2-17. Estimated Risk of Seismic Activity in the Conterminous States (Source: 1979 Uniform Building Code)

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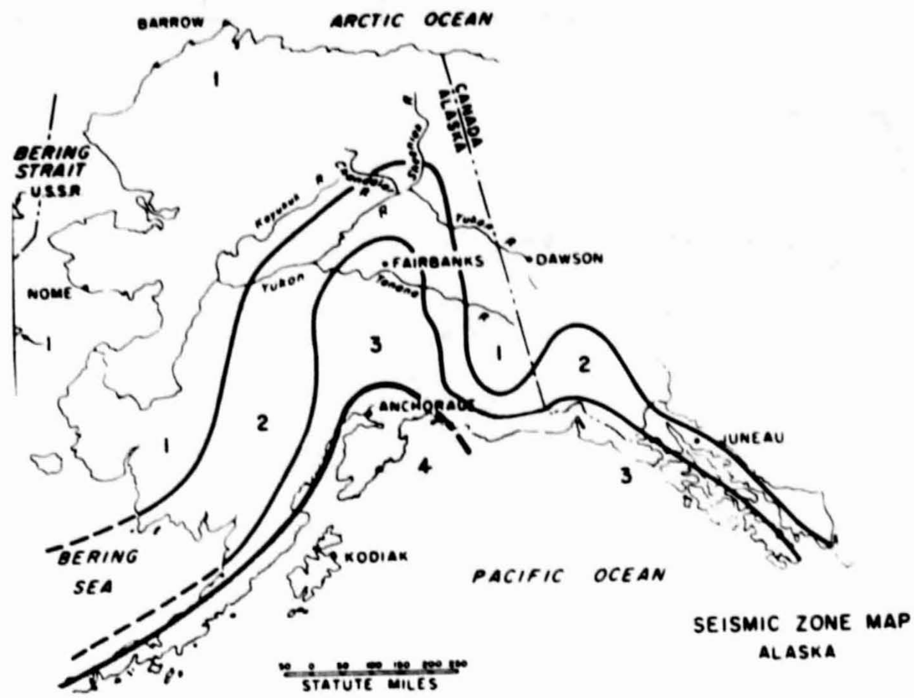

Figure 2-18. Estimated Risk of Seismic Activity: Alaska (Source: 1979 Uniform Building Code)

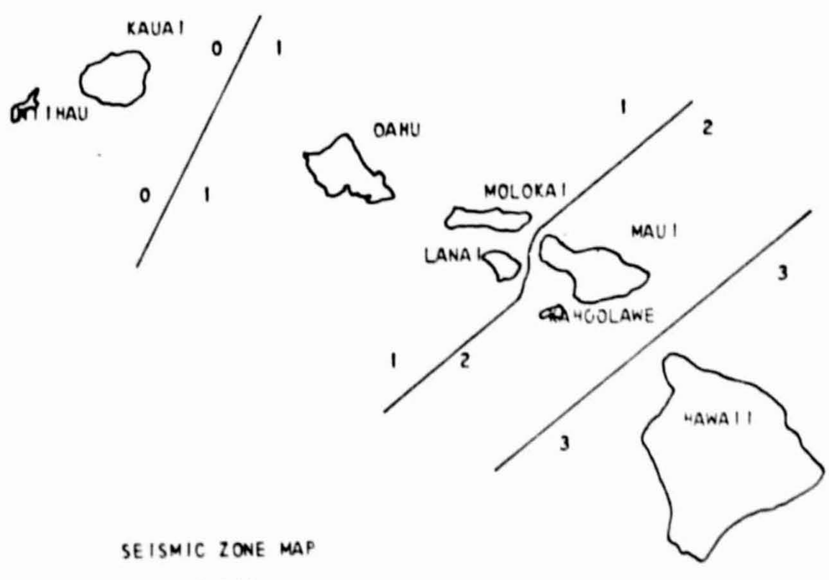

Figure 2-19. Estimated Risk of Seismic Activity: Hawaii (Source: 1979 Uniform Building Code)

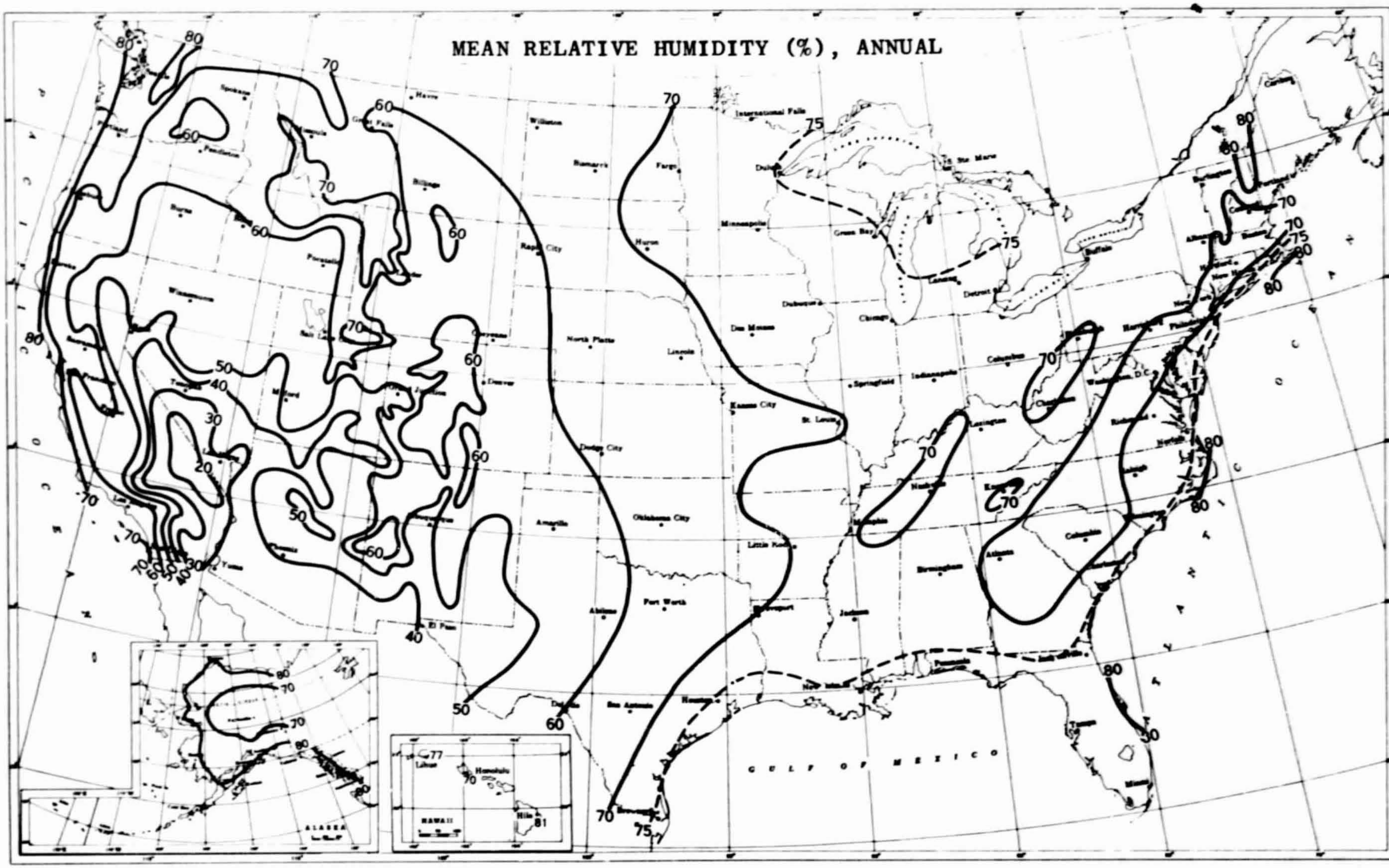

Figure 2-20. Annual Average Relative Humidity, % (Source: U.S. Department of Commerce, 1979)

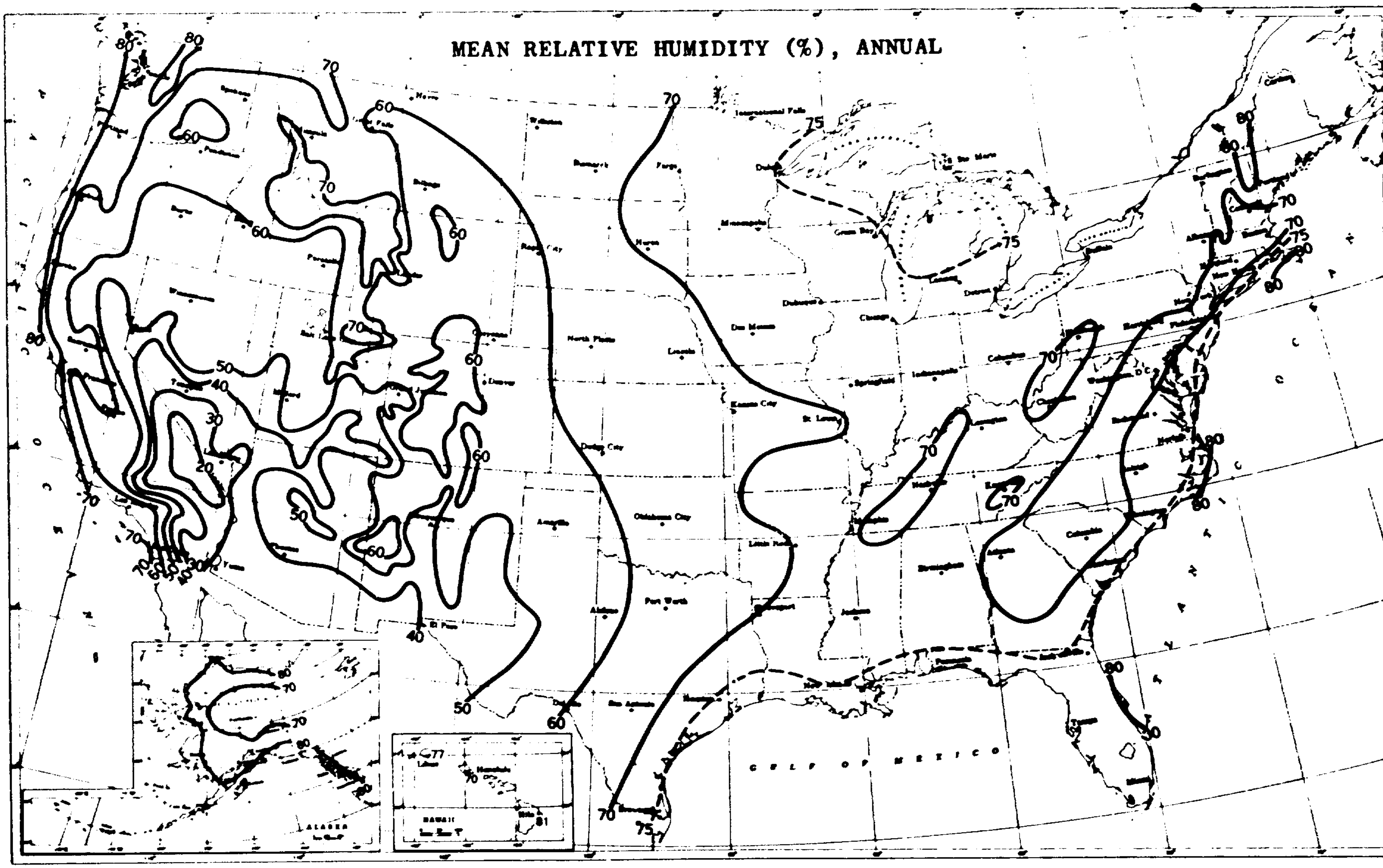

Figure 2-20. Annual Average Relative Humidity, % (Source: U.S. Department of Commerce, 1979)

west-central between 60 and 70%. In the western states, humidity between 40 and 60% is shown, except for the southwestern deserts, ranging from 20 to 40%. In Alaska, annual average humidity ranges from 70 to 80% year around, except for the coastal area, where 90% average humidities are recorded during the summer. On the whole, relative humidity is not a function of the time of year. The annual swing in humidity ranges from 10% in the East to 20% in the deserts.

Relative humidity is a major factor in the rate of evaporation. The direct effects of humidity are of second-order importance. In very humid conditions, with ambient temperature above pond surface temperature, significant condensation (dew) may occur at the pond surface, slightly heating the pond. Radiative heat loss from the pond surface is reduced when atmospheric moisture increases. High humidity, especially at high ambient temperatures, would reduce both evaporation and radiation.

SECTION 3

REGIONAL CHARACTERISTICS OF SOLAR PONDS

3.1 DEFINITION OF GEOGRAPHIC REGIONS

3.1.1 Rationale and Criteria

The availability of the four natural resources (sunshine, land, water and salts) that are essential to a solar pond varies from one locale to another, as is evident from Section 2.1. The physical parameters that affect a pond's operation and performance also change with location and time, as discussed in Section 2.2. However, a site-by-site evaluation of solar pond applicability and potential is too detailed and would not comprehensively cover the entire United States within the specified scope of the present study. A regional-level evaluation thus becomes a logical approach. Upon examination of the requisite natural resources and pertinent physical parameters (Section 2), it appears that the patterns of variation for many of the technical factors can generally be discerned on a regional basis. Consequently, it is useful to delineate regions of similar characteristics as concerns solar ponds. A regional study will encompass the entire United States and the various major market sectors while ignoring the finer local variances. To guide the definition of regions, a number of criteria were utilized:

(1) The number of regions defined must be small enough to be manageable, and large enough to capture the significant details. Preferably, there should be 10 to 20 regions.

(2) Defined regions should display similar pond-related characteristics within the region. Different regions should reflect either different degrees of availability of the four essential natural resources, or differences in the physical parameters that affect solar pond performance.

(3) Region boundaries should follow state boundaries as much as possible, for information-handling and other conveniences. Where region boundaries must cut through states, simple straight boundaries are preferred.

3.1.2 Defined Regions and General Features

Insolation level, water, and salts availability are the primary factors considered in defining the regions. Temperature distribution is also considered, but in a lesser role. Patterns for precipitation and relative humidity appear to be similar and are reflected in water availability. The pattern for evaporation agrees roughly with that for insolation, so evaporation is not considered independently. The availability of land, land cost, topography, ground-water depth and soil conditions are site-specific and thus are not included in the region definition. Secondary factors, including seismic

activity, wind velocity, and hurricane and tornado occurrences, were not considered in the region definition, but they can significantly influence pond design and performance and should not be neglected in any specific pond design.

Based on the above criteria and considerations, the United States was divided into 12 regions. The regions and the states (or territory) which they cover are tabulated in Table 3-1 and mapped in Figure 3-1. Several features about these regions are noteworthy:

(1) The nine regions within the conterminous United States can be grouped to approximately follow the insolation contours in the following manner (Fig. 3-1):

Highest insolation:	the Southwest region
High insolation:	the Pacific Northwest, Black Hills, Great Lakes, Tennessee Valley and Gulf Coast regions
Low insolation:	the Atlantic Northeast region

(2) The Alaska, Hawaii, and Puerto Rico regions are separate regions because of their distinct geographic locations.

(3) The regions west of the Black Hills and Red River regions inclusive tend to suffer from water shortage, while those east of these two regions generally have an abundance of water. (See Fig. 2-5 and 2-10 through 2-12 for maps on precipitation and surface-water runoff.)

(4) Natural salts (in the form of rock-salt deposits or saline surface water) are available in the Gulf Coast, Red River, Southwest, Salt Lake and Black Hills regions in relatively large quantities. (See Fig. 2-7 and F-1 for maps on rock-salt deposits and saline surface water, respectively.)

(5) High temperature prevails in the Gulf Coast region and the southern halves of the Southwest and Red River regions. The region boundaries running east-west roughly parallel the temperature contours. (See Fig. 2-8 for temperature maps.)

(6) All region boundaries coincide with state boundaries except in California and Nevada where insolation contours cut across the states. Expedient straight region boundaries are drawn placing the northern halves of California and Nevada in the Salt Lake region and southern halves of these states in the Southwest region.

(7) The regions were assigned easily recognizable names. The names Salt Lake, Red River and Tennessee Valley are geographically less encompassing, but refer to the potential solar pond developments in the Great Salt Lake, Red River and Tennessee Valley areas.

Table 3-1. Solar Poud Regions

Region	State/Territory
Alaska	Alaska
Atlantic Northeast	Connecticut
	Maine
	Massachusetts
	New Hampshire
	New Jersey
	New York
	Pennsylvania
	Rhode Island
	Vermont
Black Hills	Montana
	Nebraska
	North Dakota
	South Dakota
	Wyoming
Great Lakes	Illinois
	Indiana
	Iowa
	Michigan
	Minnesota
	Ohio
	Wisconsin
Gulf Coast	Alabama
	Florida
	Georgia
	Louisiana
	Mississippi
	South Carolina
Hawaii	Hawaii
Pacific Northwest	Idaho
	Oregon
	Washington
Puerto Rico	Puerto Rico
Red River	Kansas
	Oklahoma
	Texas

Table 3-1. (Cont'd)

Region	State/Territory
Salt Lake	California (northern) Colorado Nevada (northern) Utah
Southwest	Arizona California (southern) Nevada (southern) New Mexico
Tennessee Valley	Arkansas Delaware Kentucky Maryland Missouri North Carolina Tennessee Virginia West Virginia

Note that regions have also been defined for many other purposes resulting in such diverse classifications as "Census Regions," "Water Resources Regions," etc. The solar pond regions defined here do not share common features with most of these. However, they appear to correspond closely to the "solar climates map" generated by Willmott and Vernon (1980) based on rather elaborate climatological analysis.

3.2 REGIONAL THERMAL AND ELECTRICAL ENERGY OUTPUT FROM SOLAR PONDS

3.2.1 Brief Description of the JPL Solar Pond Performance Model

The JPL solar pond computer code is a design tool that calculates pond thermal performance for a given set of specified design and operating conditions. The code is based on a finite-difference solution of the one-dimensional heat conduction equation with a source term representing absorption of insolation as a function of depth. The code is applicable to large ponds (larger than a few acres) where edge effects are assumed to be insignificant.

The specified design parameters (code input) include:

(1) Depth of the upper convecting zone, middle nonconvecting zone and lower convecting zone.

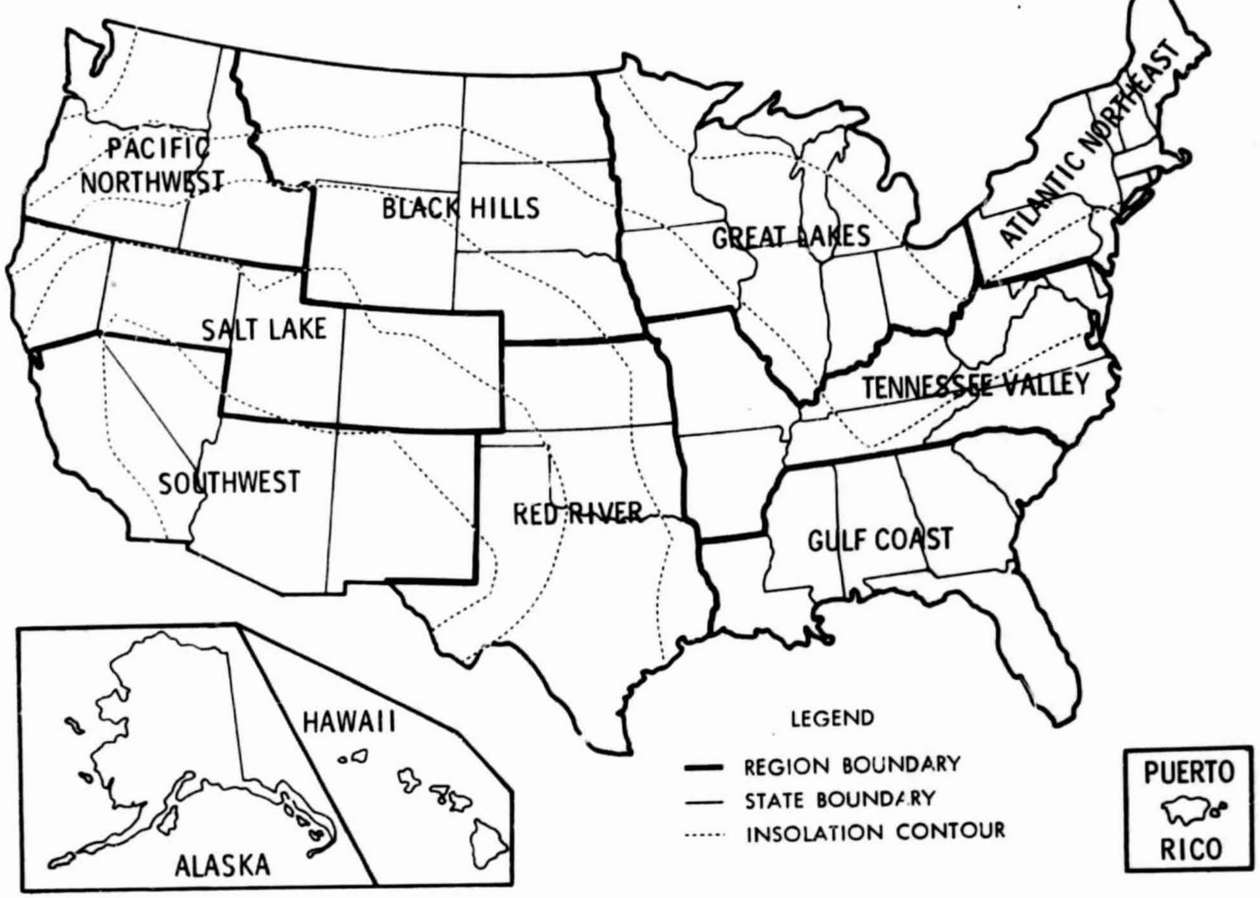

Figure 3-1. Regions Defined for the Evaluation of Solar Pond Applicability and Potential

(2) Surface area.

(3) Monthly values for total insolation and ambient temperature.

(4) Site latitude.

(5) Water optical data in terms of transmittance of insolation as a function of salinity and wavelength.

(6) Upper convecting and lower convecting zone salinity.

The specified operating conditions include either (1) a lower convecting zone temperature for constant temperature thermal extraction, (2) an annual temperature profile for the lower convecting zone, or (3) monthly thermal loads and a minimum extraction temperature.

Outputs from the code include a history (from start of pond warm-up) of pond temperature as a function of depth, and the rate of thermal energy output and, if desired, the gross and net rates of electrical power generation from a heat engine operating at 64% of Carnot efficiency. The parasitic power requirement is 22.8% of the gross electrical power output.

The pond model considers four zones. The upper convecting zone (UCZ) is a surface layer from 0.15 to 0.25 m thick. The middle nonconvecting zone (MNZ), characterized by the presence of vertical salinity, density, and temperature gradients, is typically 0.80 to 1.30 m thick and provides thermal insulation for the lower convecting zone (LCZ), where solar energy is collected and stored. The LCZ is typically 1.00 to 3.50 m thick. The ground (GRD) serves to increase the thermal capacity of the pond.

The UCZ and LCZ are modeled as isothermal and the temperature of the MNZ and GRD is computed as a function of both time and depth. The temperature in the UCZ is equated to the ambient temperature. The lateral temperature variance in all zones is considered to be negligible and thermal losses through the pond perimeter are ignored. This approximation appears reasonable for large-scale ponds. (For further details concerning the model and a comparison of simulation results from the JPL and other models, see Appendix H.)

3.2.2 Basis of Regional Performance Estimates and Comparison

Solar pond thermal and electrical power performance was estimated for one site in each of the 12 regions defined in Section 3.1. A geographically centralized site was chosen in each region so that the site performance estimates may be regarded as representative of those within the region (Table 3-2). When interpreting the representative site estimates, however, note that performance can vary considerably within a given region.

Annual-average rates of thermal or electrical output vary as functions of design and operating specifications. To provide an equitable basis for comparing regional pond performances, one common set of design and operating specifications was chosen for all sites.

Table 3-2. Selected Sites for Regional Performance Estimates[a]

Region	Site	Latitude	Longitude	Annual-average Ambient Temp °C	Annual-average Total Insolation W/m^2
Southwest	Daggett, Calif.	34°52'N	117°41'W	19.1	243
Salt Lake	Salt Lake City, Utah	40°46'	111°58'	10.6	211
Red River	Forth Worth, Tex.	32°50'	97°03	18.6	194
Pacific Northwest	Pendleton, Oreg.	45°41'	118°51'	11.3	165
Black Hills	Huron, S. Dak.	44°23'	98°13'	7.1	168
Great Lakes	Madison, Wis.	43°08'	89°20'	7.2	157
Tennessee Valley	Memphis, Tenn.	35°13'	89°59'	16.4	180
Gulf Coast	Jackson, Miss.	32°19'	90°05'	18.3	186
Atlantic Northeast	Albany, N.Y.	42°45'	73°48'	8.7	140
Alaska	Fairbanks, Alaska	64°49'	147°52'	-3.5	101
Hawaii	Honolulu, Hawaii	21°20'	157°55'	24.8	216
Puerto Rico	San Juan, P.R.	18°26'	66°00'	25.9	216

[a]Data from Appendix B, Section 2.

The upper convecting zone, middle nonconvecting zone and lower convecting zone thicknesses were set at 0.25 m, 1.30 m and 3.00 m, respectively. These values represented reasonable choices for a typical "deep" pond. The lower convecting zone and upper convecting zone salinities were set at 0.03 and 0.22 weight fraction, respectively.

Optical properties of water generally vary considerably from site to site. The regional performance calculations were based on water clarity equivalent to that of Salton Sea water that has been clarified by treatment with activated carbon. Thermal properties of water and ground can also vary considerably from site to site. The calculations assume that the thermal capacitance of the ground is equivalent to that of saline water at the salinity of the lower convecting zone. The thermal conductivity of the ground is approximated by three times the value for saline water. These values appear reasonable in comparison to the data available for different earth types.

The model allows for a thin, opaque ice cover to form when the average daily ambient temperature falls below -6°C. This condition applies to Huron, Madison, and Fairbanks.

The energy extraction was performed for all sites when the pond storage zone temperature reached 45 or 60°C for a thermal application, and 75 or 85°C in the case of electric power production. Because load-matching extraction for different applications generally will require varying extraction temperatures, this mode does not represent all applications, but most closely simulates the performance of a summer or fall-peaking pond, and is suitable for such applications as crop drying and summer-peaking electric power generation. However, it appears to be appropriate for providing a common basis for comparing pond performance in the 12 defined regions. It must be recognized that, in actual practice, the pond system design will be optimized and the optimization will include establishing an energy extraction schedule which best suits the application under consideration.

3.2.3 Thermal Energy Output

Performance estimates for solar pond thermal energy output at the 12 sites are given in Table 3-3, along with the parasitic power requirement for brine pumping and gradient maintenance.

The 45 and 60°C extraction temperatures represent typical pond temperatures for low temperature thermal applications. System design should account for a temperature drop across the heat exchanger of about 5 or 6°C.

As shown, the thermal output is a strong function of climatic conditions (especially insolation), ranging from 6.9 Wt/m^2 in Fairbanks to 73.1 Wt/m^2 in Daggett at an extraction temperature of 45°C, and from 0.0 Wt/m^2 in Fairbanks to 63.2 Wt/m^2 in Daggett at 60°C.

The output figures in Table 3-3 are for the fourth year of pond operation, when operating conditions approach the steady state. Output estimates for later years may be slightly higher, but not appreciably.

Although the estimates in Table 3-3 constitute a reasonable common basis for regional comparison, site-specific analysis must be performed for an actual application design.

Note that thermal energy output calculations as presented in Table 3-3 imply higher thermal efficiencies (20 to 27% for the high-insolation regions at a heat extraction temperature of 60°C) than experience with existing ponds to date would indicate. Because energy output estimates will play an important role in subsequent economic analysis, both the computer calculations and existing pond data were closely examined. It was determined that:

(1) The thermal efficiency of a solar pond is affected by a number of factors: the pond size (smaller ponds have higher heat losses through the sides); how closely the operating conditions have approached steady-state (e.g., the fourth-year output is expected to be significantly higher than the first-year output); the value of thermal conductivity of the surrounding ground; the specified heat-extraction temperature (higher extraction temperatures lead to lower thermal efficiencies; see Tables 3-3 and 3-4); heat extraction pattern; optical properties of brine; thicknesses of the surface, gradient and storage zones; salinity profiles; climatic conditions; etc.

(2) Simulation results from the JPL pond model have been shown to be in reasonable agreement with those obtained independently from the Ormat and SERI models (see Appendix H, Tables H-2 through H-4). While extensive validation of these three models is yet to be conducted, judging from results of preliminary validations and the reasonable agreement demonstrated among the three models, it is believed that the JPL model is valid when used to predict the performance of relatively large ponds (i.e., 1 acre or larger).

(3) Assumptions on the various parameters that were made for calculating regional pond energy output (see Section 3.2.2) were scrutinized. Compared with performance data from the existing ponds, these assumptions appear reasonable and justifiable.

(4) All of the existing ponds in the United States are small (no larger than 1/2 acre). Except for the newly constructed ones, most have not been operated with the objective of maximizing energy output in mind. Actual thermal efficiency data from these ponds are sketchy and indicate low thermal efficiencies, i.e., well below 15% (see the survey reported by Lin, 1982). Large edge heat losses and non-optimal heat extraction are recognized to contribute to the low efficiencies. Future heat balance data are expected to yield higher efficiency values. Furthermore, data from the first-year operation of the Ein Bokek pond, Israel, show a maximum thermal efficiency of 19.4% during a week in July 1980. (See the survey reported by Lin, 1982.) Considering that the heat

extraction temperature in this case was well over 65°C and that operating conditions of the pond were far from reaching steady state, future efficiency data could turn out to be substantially higher than 20%, particularly if heat extraction were to be performed at a lower temperature (60°C), as would be the case for thermal applications.

Based on the above considerations, it is concluded that using the calculated pond energy output (as tabulated in Tables 3-3 and 3-4) as a basis for regional assessment of solar pond applicability and potential is reasonable and justifiable. In the absence of an adequate data base for solar ponds' thermal efficiencies, the calculated values provide the best energy output estimates that are consistent and suitable for an equitable regional comparison.

3.2.4 Electrical Power Output

Performance estimates for electrical power generation at the 12 sites are given in Table 3-4. Thermal energy was extracted from the ponds at constant temperatures of 85 and 75°C. The former temperature is the design point assumed by Ormat for the Salton Sea Solar Pond. Because of the specified constant-temperature extraction criterion, electrical output is zero for at least part of the year at all sites except Daggett, Honolulu, and San Juan at an extraction temperature of 75°C, and for all sites except Honolulu and San Juan at 85°C.

Note that for Daggett, Honolulu, and San Juan the annual-average rate of power production is greater at 85°C than at 75°C, whereas the reverse is true for the remaining sites. This is the result of the trade-off between two competing factors. As the extraction temperature is raised, the thermal-to-electric conversion efficiency is increased, but both the pond thermal efficiency ard the plant capacity factor are reduced. For the sites with higher insolation, such as Daggett, Honolulu and San Juan, the gain in the former is more than enough to offset the loss in the latter. But for the sites with lower insolation, the effect of the reduction in the latter is more pronounced. Because an optimized plant design can reasonably be expected to produce higher electrical energy than indicated by either column of Table 3-4, the higher output figures from the two columns are recommended.

Table 3-3. Regional Estimates of Thermal Energy Output from Solar Ponds[a]

Region	Site	60°C Heat Extraction Thermal Output W_{th}/m^2	60°C Heat Extraction Parasitic Power[b] W_e/m^2	45°C Heat Extraction Thermal Output W_{th}/m^2	45°C Heat Extraction Parasitic Power[b] W_e/m^2
Southwest	Daggett, Calif.	63.2	0.47	73.1	0.54
Salt Lake	Salt Lake City, Utah	46.2	0.35	55.9	0.42
Red River	Fort Worth, Tex.	45.3	0.35	55.2	0.42
Pacific Northwest	Pendleton, Oreg.	31.9	0.25	41.1	0.32
Black Hills	Huron, S. Dak.	25.3	0.21	34.1	0.27
Great Lakes	Madison, Wis.	22.3	0.19	31.1	0.25
Tennessee Valley	Memphis, Tenn.	38.6	0.30	48.4	0.37
Gulf Coast	Jackson, Miss.	41.9	0.32	51.8	0.39
Atlantic Northeast	Albany, N.Y.	20.0	0.17	29.0	0.23
Alaska	Fairbanks, Alaska	0.0	0.03	6.9	0.08
Hawaii	Honolulu, Hawaii	57.9	0.44	67.8	0.50
Puerto Rico	San Juan, P.R.	58.7	0.44	68.6	0.51

[a]Thermal output during fourth year of solar pond operation. For a detailed discussion on thermal efficiency see Section 3.2.3.

[b]The parasitic power is for water make-up (ca. 0.025 W_e/m^2), surface flushing (ca. 0.005 W_e/m^2), brine supply (ca. 0.001 W_e/m^2), and for circulating the hot brine (approximated as 0.380 x heat out/54.46 W_e/m^2).

Table 3-4. Regional Estimates of Electric Power Output from Solar Ponds

Region	Site	Net Electrical Power Output (W_e/m^2)[a] Heat Extraction at: 75°C	85°C
Southwest	Daggett, Calif.	2.98	3.11
Salt Lake	Salt Lake City, Utah	2.31	2.25
Red River	Fort Worth, Tex.	1.94	1.87
Pacific Northwest	Pendleton, Oreg.	1.43	1.25
Black Hills	Huron, S. Dak.	1.01	0.79
Great Lakes	Madison, Wis.	0.84	0.58
Tennessee Valley	Memphis, Tenn.	1.61	1.49
Gulf Coast	Jackson, Miss.	1.80	1.69
Atlantic Northeast	Albany, N.Y.	0.68	0.39
Alaska	Fairbanks, Alaska	0.00	0.00
Hawaii	Honolulu, Hawaii	2.60	2.71
Puerto Rico	San Juan, P.R.	2.58	2.72

[a]Power generation during fourth year of operation. The calculations lump the small parasitic load (ca. 0.03 W_e/m^2) for surface flushing, water make-up and brine make-up with the much larger parasitic loads for power cycle pumping. That is, all parasitic loads are assumed proportional to the rate of power plant electrical output.

SECTION 4

SOLAR POND SYSTEM DESIGN CASE STUDIES

4.1 POND SUBSYSTEM

4.1.1 Description of Study Cases

Solar pond design is influenced by a number of factors, chief among which are insolation level, water transparency, energy extraction mode (base-load or peaking operation, delivery temperatures, flow rates, etc.), and local climatic conditions. The performance of a pond is a function of both the geographic region and the characteristics of the specific application.

Twenty-four application cases were selected, for which Ormat Turbines, Ltd. of Israel, under a subcontract with JPL, conducted studies to determine solar pond design and performance parameters. The study cases were intended to provide information on the application of solar ponds to residential space and water heating, certain agricultural and industrial process heating, and electric power generation, in a manner that allows regional comparison of pond sizing and performance. Results of these case studies are also expected to provide pond designers/users with some reference cases which may serve as a guide for future work.

The 24 selected cases are listed in Table 4-1. Cases 1 through 10 deal with space and water heating in 10 different regions for a 120,000-ft^2 low-rise apartment complex. The Puerto Rico and Hawaii regions are precluded from the space heating application study because of their warm winter climate.

Monthly energy requirements for Cases 1 through 10 are tabulated in Tables 4-2 through 4-11. The apartment space heating energy requirement profiles for these cases were essentially based on a 1974 General Electric report (NSF-RA-N-74-021C). The domestic water heating energy needs were based on typical average household consumption (80 gal/day) adjusted for the size of the apartment complex.

Hot water for household use requires a temperature from 120 to 140°F. Hot water for sanitary purposes such as in hospitals and cafeterias requires a temperature of 180°F. Conventionally, hot air circulation for space heating requires a temperature of from 90 to 120°F depending on the heating system design and air circulation distance. In addition, a 10 to 20°F temperature drop must be allowed across a heat exchanger if it is utilized in the heating system.

Water heating for a representative poultry dressing plant in six different regions is addressed in Cases 11, 12, and 18 through 21. The heating requirement is constant throughout the year at the rate of 2275 MBtu/month. A 10 to 20°F temperature drop across the brine-freshwater heat exchanger was allowed. The inlet temperature of the process water was specified to be 60°F, and the delivery temperature was to be chosen from among 140°, 130° and 120°F constant throughout the year. These cases will serve as examples of constant-load pond operation which is characteristic of many industrial process heating applications.

Table 4-1. Summary of Pond-Subsystem Design Study Cases

Case No.	Application and Region
1	Apartment space and water heating, Atlantic Northeast Region
2	Apartment space and water heating, Tennessee Valley Region
3	Apartment space and water heating, Gulf Coast Region
4	Apartment space and water heating, Great Lakes Region
5	Apartment space and water heating, Black Hills Region
6	Apartment space and water heating, Red River Region
7	Apartment space and water heating, Pacific Northwest Region
8	Apartment space and water heating, Salt Lake Region
9	Apartment space and water heating, Southwest Region
10	Apartment space and water heating, Alaska Region
11	Poultry dressing plants application, Atlantic Northeast Region
12	Poultry dressing plants application, Southwest Region
[illegible]	Seasonal water heating at canning plant, Southwest Region
14	Frozen foods plant application, Southwest Region
15	Seasonal crop drying, Great Lakes Region
16	Seasonal crop drying, Red River Region
17	Farm house heating and crop drying, Great Lakes Region
18	Poultry dressing plants application, Red River Region
19	Poultry dressing plants application, Great Lakes Region
20	Poultry dressing plants application, Pacific Northwest Region
21	Poultry dressing plants application, Gulf Coast Region
22	Base-load electric power generation, Salt Lake Region
23	Peak-load electric power generation, Salt Lake Region
24	Peak-load electric power generation, Great Lakes Region

Table 4-2. Case 1. Monthly Energy Requirement. Space and Water Heating for a 120,000-ft^2 Apartment Complex Located in Boston, Mass. Atlantic Northeast Region

Month	Space Heating	Water Heating	Total
Jan.	613.2	149.6	762.8
Feb.	499.2	149.6	648.8
Mar.	454.8	149.6	604.4
Apr.	400.8	149.6	550.4
May	181.2	138.4	319.6
Jun.	21.6	128.0	149.6
Jul.	0	128.0	128.0
Aug.	0	128.0	128.0
Sep.	84.0	138.4	222.4
Oct.	184.8	149.6	334.4
Nov.	412.8	149.6	562.4
Dec.	660.0	149.6	809.6
Total	3511.2	1708.0	5219.2

Table 4-3. Case 2. Monthly Energy Requirement. Space and Water Heating for a 120,000-ft^2 Apartment Complex Located in Nashville, Tenn. Tennessee Valley Region

Month	Space Heating	Water Heating	Total
Jan.	517.2	149.6	666.8
Feb.	419.8	149.6	569.4
Mar.	327.3	149.6	476.9
Apr.	109.9	149.6	259.5
May	28.1	138.4	166.5
Jun.	0	128.0	128.0
Jul.	0	128.0	128.0
Aug.	0	128.0	128.0
Sep.	6.3	138.4	144.7
Oct.	112.4	149.6	262.0
Nov.	311.1	149.6	460.7
Dec.	476.6	149.6	626.2
Total	2308.7	1708.0	4016.7

Table 4-4. Case 3. Monthly Energy Requirement. Space and Water Heating for a 120,000-ft^2 Apartment Complex Located in Atlanta, Ga. Gulf Coast Region

Month	Space Heating	Water Heating	Total
Jan.	437.9	149.6	587.5
Feb.	349.8	149.6	499.4
Mar.	276.7	149.6	426.3
Apr.	90.0	149.6	239.6
May	16.0	138.4	155.3
Jun.	0	128.0	128.0
Jul.	0	128.0	128.0
Aug.	0	128.0	128.0
Sep.	5.0	138.4	143.4
Oct.	85.6	149.6	235.2
Nov.	254.9	149.6	404.5
Dec.	416.6	149.6	566.2
Total	1933.3	1708.0	3641.3

Table 4-5. Case 4. Monthly Energy Requirement. Space and Water Heating for a 120,000-ft^2 Apartment Complex Located in Madison, Wis. Great Lakes Region

Month	Space Heating	Water Heating	Total
Jan.	933.2	149.6	1082.8
Feb.	782.1	149.6	931.7
Mar.	674.0	149.6	823.6
Apr.	369.2	149.6	518.8
May	185.5	138.4	323.9
Jun.	45.0	128.0	173.0
Jul.	8.7	128.0	136.7
Aug.	24.4	128.0	152.4
Sep.	108.1	138.4	246.5
Oct.	296.1	149.6	445.7
Nov.	567.8	149.6	717.4
Dec.	834.5	149.6	984.1
Total	4828.6	1708.0	6536.6

Table 4-6. Case 5. Monthly Energy Requirement. Space and Water Heating for a 120,000-ft^2 Apartment Complex Located in Bismark, N.Dak. Black Hills Region

Month	Space Heating	Water Heating	Total
Jan.	772.5	149.6	922.1
Feb.	632.5	149.6	782.1
Mar.	542.6	149.6	692.2
Apr.	289.5	149.6	439.1
May	148.7	138.4	287.1
Jun.	53.5	128.0	181.5
Jul.	7.9	128.0	135.9
Aug.	15.4	128.0	143.4
Sep.	110.5	138.4	284.9
Oct.	247.4	149.6	397.0
Nov.	475.1	149.6	624.7
Dec.	671.6	149.6	821.2
Total	3967.2	1708.0	5675.2

Table 4-7. Case 6. Monthly Energy Requirement. Space and Water Heating for a 120,000-ft^2 Apartment Complex Located in Fort Worth, Tex. Red River Region

Month	Space Heating	Water Heating	Total
Jan.	391.0	149.6	540.6
Feb.	284.8	149.6	434.4
Mar.	209.3	149.6	358.9
Apr.	55.0	149.6	204.6
May	0	138.4	138.4
Jun.	0	128.0	128.0
Jul.	0	128.0	128.0
Aug.	0	128.0	128.0
Sep.	0	138.4	138.4
Oct.	37.5	149.6	187.1
Nov.	179.3	149.6	328.9
Dec.	331.1	149.6	480.7
Total	1487.9	1708.0	3195.9

Table 4-8. Case 7. Monthly Energy Requirement. Space and Water Heating for a 120,000-ft^2 Apartment Complex Located in Seattle, Wash. Pacific Northwest Region

Month	Space Heating	Water Heating	Total
Jan.	519.1	149.6	668.7
Feb.	397.3	149.6	546.9
Mar.	404.8	149.6	554.4
Apr.	305.5	149.6	455.1
May	195.5	138.4	333.9
Jun.	104.3	128.0	232.3
Jul.	50.0	128.0	178.0
Aug.	51.2	128.0	179.2
Sep.	106.2	138.4	244.6
Oct.	248.0	149.6	397.6
Nov.	382.3	149.6	531.9
Dec.	474.7	149.6	624.3
Total	3238.8	1708.0	4946.8

Table 4-9. Case 8. Monthly Energy Requirement. Space and Water Heating for a 120,000-ft^2 Apartment Complex Located in Salt Lake City, Utah. Salt Lake Region

Month	Space Heating	Water Heating	Total
Jan.	716.5	149.6	866.1
Feb.	552.8	149.6	702.4
Mar.	491.6	149.6	641.2
Apr.	296.1	149.6	445.7
May	148.0	138.4	286.4
Jun.	55.0	128.0	183.0
Jul.	0	128.0	128.0
Aug.	3.1	128.0	131.1
Sep.	65.6	138.4	204.0
Oct.	251.1	149.6	400.7
Nov.	485.4	149.6	635.0
Dec.	672.1	149.6	821.7
Total	3737.3	1708.0	5445.3

Table 4-10. Case 9. Monthly Energy Requirement. Space and Water Heating for a 120,000-ft^2 Apartment Complex Located in Phoenix, Ariz. Southwest Region

Month	Space Heating	Water Heating	Total
Jan.	267.4	149.6	417.0
Feb.	182.4	149.6	332.0
Mar.	115.6	149.6	265.2
Apr.	37.5	149.6	187.1
May	0	138.4	138.4
Jun.	0	128.0	128.0
Jul.	0	128.0	128.0
Aug.	0	128.0	128.0
Sep.	0	138.4	138.4
Oct.	10.6	149.6	160.2
Nov.	113.7	149.6	263.3
Dec.	242.4	149.6	392.0
Total	969.5	1708.0	2677.5

Table 4-11. Case 10. Monthly Energy Requirement. Space and Water Heating for a 120,000-ft^2 Apartment Complex Located in Fairbanks, Alas. Alaska Region

Month	Space Heating	Water Heating	Total
Jan.	1489.2	149.6	1638.8
Feb.	1180.6	149.6	1330.2
Mar.	1074.4	149.6	1224.0
Apr.	676.5	149.6	826.1
May	342.9	138.4	481.3
Jun.	131.8	128.0	259.8
Jul.	92.4	128.0	220.4
Aug.	189.9	128.0	317.9
Sep.	386.0	138.4	524.4
Oct.	770.8	149.6	920.4
Nov.	1165.6	149.6	1315.2
Dec.	1459.8	149.6	1609.4
Total	8960.1	1708.0	10,668.1

Case 13 is a seasonal water heating application with a seasonal load for a canning plant in Stockton, California. The solar pond is required to heat freshwater from 60 to 180°F (or 170°F or 160°F) at the rate of 8635 MBtu/month from July 15 through October 15. A 10 to 20°F temperature drop across the brine-freshwater heat exchanger was specified. About 35% of the canned fruits and vegetables produced in the United States are from California. This plant is typical of California canneries, operating from mid-July until mid-October and consuming about 288,000 gal of 180°F water per day during that period.

In Case 14, hot water is required for a frozen foods plant located in Phoenix. Similar to Cases 11, 12, and 18 through 21, heat is to be provided by a solar pond at a constant monthly rate of 2167 MBtu/month with a delivery temperature of 180°, 170°, 160° or 150°F. Again, a 10 to 20°F temperature drop across the brine-freshwater heat exchanger is assumed.

Seasonal crop drying is represented by Cases 15 and 16 with the pond having to provide 8666 MBtu/month for October through December, and no heat required for the remainder of the year. Heat transfer from the pond is accomplished by circulating pond water through water-air heat exchangers, sized such that the water (brine) is at a minimum temperature of 60°F above the ambient air temperature as it exits the pond. Two sites are studied: Des Moines, Iowa, and Fort Worth, Texas. The ambient air temperature for Des Moines is 55°F in October, 37°F in November and 26°F in December. The corresponding ambient air temperatures for Fort Worth, are 67°, 55° and 47°F, respectively.

Case 17 represents farmhouse heating and crop drying in the Chicago area. Pond output requirement and minimum brine temperature vary each month throughout the year, as shown in Figures 4-1 and 4-2, respectively.

Solar ponds can also be used to generate either base-load or peaking electric power in regions of high insolation. Case 22 considers a 5-MW base-load plant at the Great Salt Lake, Utah, and Cases 23 and 24 consider 5-MW summer peaking power generation at the Great Salt Lake, Utah, and Detroit, Michigan, respectively.

4.1.2 Method of Analysis

Ormat conducted the case studies with information described in the foregoing section and using their Solar Pond Behavior Model (Tabor and Weinberger, 1980). Materials contained in this section and Section 4.1.3 are extracted from a report that Ormat prepared for JPL as an account of the contract work (Ormat Turbines, Ltd., 1982).

4.1.2.1 Energy Requirements. Energy requirements for Cases 1 through 21 were specified as the energy to be provided by the solar pond. Solar ponds were sized such that these energy requirements were actually provided as an output from the ponds. In this manner, the temperature of the solar pond storage varied throughout the year in response to solar energy deposition, environmental heat losses, and thermal energy extraction.

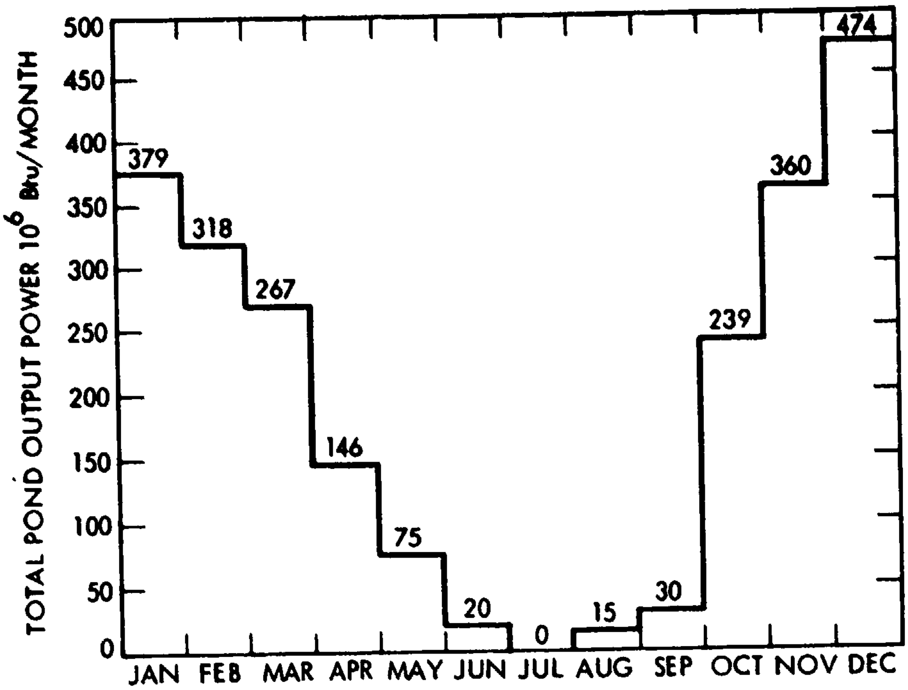

Figure 4-1. Total Power Output from Pond for Farm Space, Water Heating and Crop Drying, Chicago

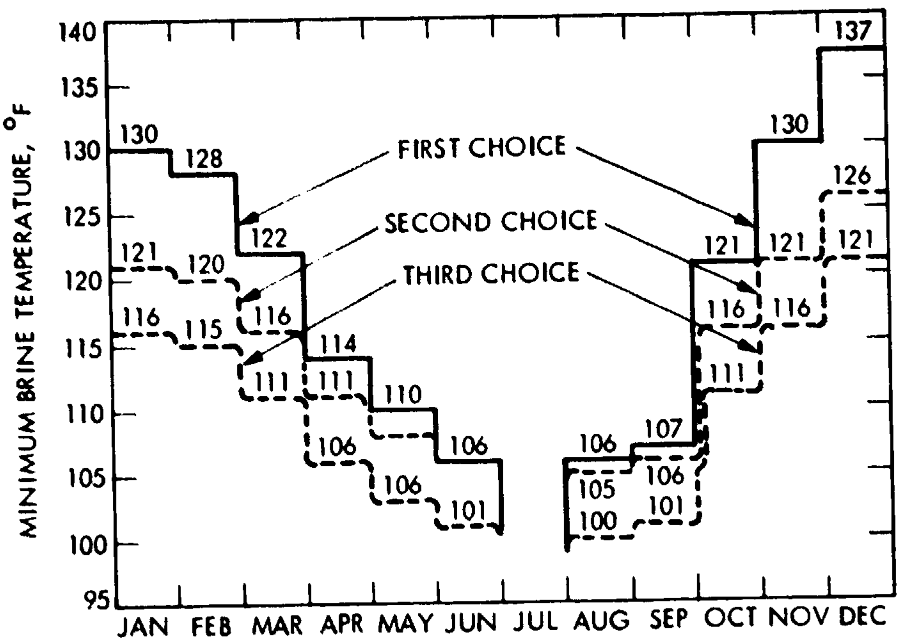

Figure 4-2. Minimum Brine Temperature for Farm Heating, Chicago

For Case 22, which considers a 5-MW base-load power plant, the solar pond behavior was modeled by extracting thermal energy during the year such that the electrical energy output is maximized.

For 5-MW peaking cases (Cases 23 and 24), the solar pond behavior was modeled such that the nominal 5-MW electrical power level was provided during the summer for the period July 1 through September 30, 24 hours a day. During the remainder of the year, January through June 30 and October 1 through December, no energy was extracted from the solar pond.

4.1.2.2 Insolation and Ambient Temperature. Monthly averaged total horizontal solar insolation and ambient temperature data are obtained from Appendix B. Such data were available for all case-study cities except Stockton, California, for which interpolation was made using data from Sacramento and Oakland.

The mean monthly temperature of a solar pond upper convective zone has been found experimentally to be within 3 to 4°F of the ambient air temperature. For purposes of this analysis, the assumptions were made that the upper convective-zone temperature was equal to the ambient air temperature and that this temperature can be approximated by a simple sinusoidal function having a period of 365 days.

Temperature Requirements. Minimum delivery temperature requirements were satisfied by sizing the solar pond such that the minimum storage-zone temperature during the year was not less than a temperature consistent with the minimum delivery temperature requirement. Figure 4-3 shows an example of brine-freshwater delivery temperature of 140°F when the minimum brine temperature is experienced at the exit of the solar pond storage zone during the period of energy extraction. In this example, it is assumed that the freshwater is heated from 60 to 140°F by the hot brine and the minimum storage-zone brine temperature during energy extraction is 150°F. Thus there is a 10°F difference across the heat exchanger between the minimum hot brine temperature (150°F) and the minimum freshwater delivery temperature (140°F). When the storage-zone temperature increases above 150°F during the year, the freshwater delivery temperature can be allowed to increase accordingly. Alternatively, the brine extraction flow rate can be reduced in order to maintain the 140°F freshwater delivery temperature throughout the year.

The 10°F temperature difference illustrated in Figure 4-3 between the minimum solar pond storage-zone temperature experienced during periods of energy extraction and the minimum freshwater delivery temperature was satisfied for Cases 1 through 14 and 18 through 21. This temperature difference is reasonable considering the resulting requirements on heat exchanger sizing and extraction flow rates (pumping requirements).

For Cases 15 through 17, the required minimum brine temperatures were satisfied by sizing the solar pond such that the storage-zone temperature did not drop below any of the minimum brine temperatures indicated during the month in which the temperature was to be maintained. Storage-zone temperatures

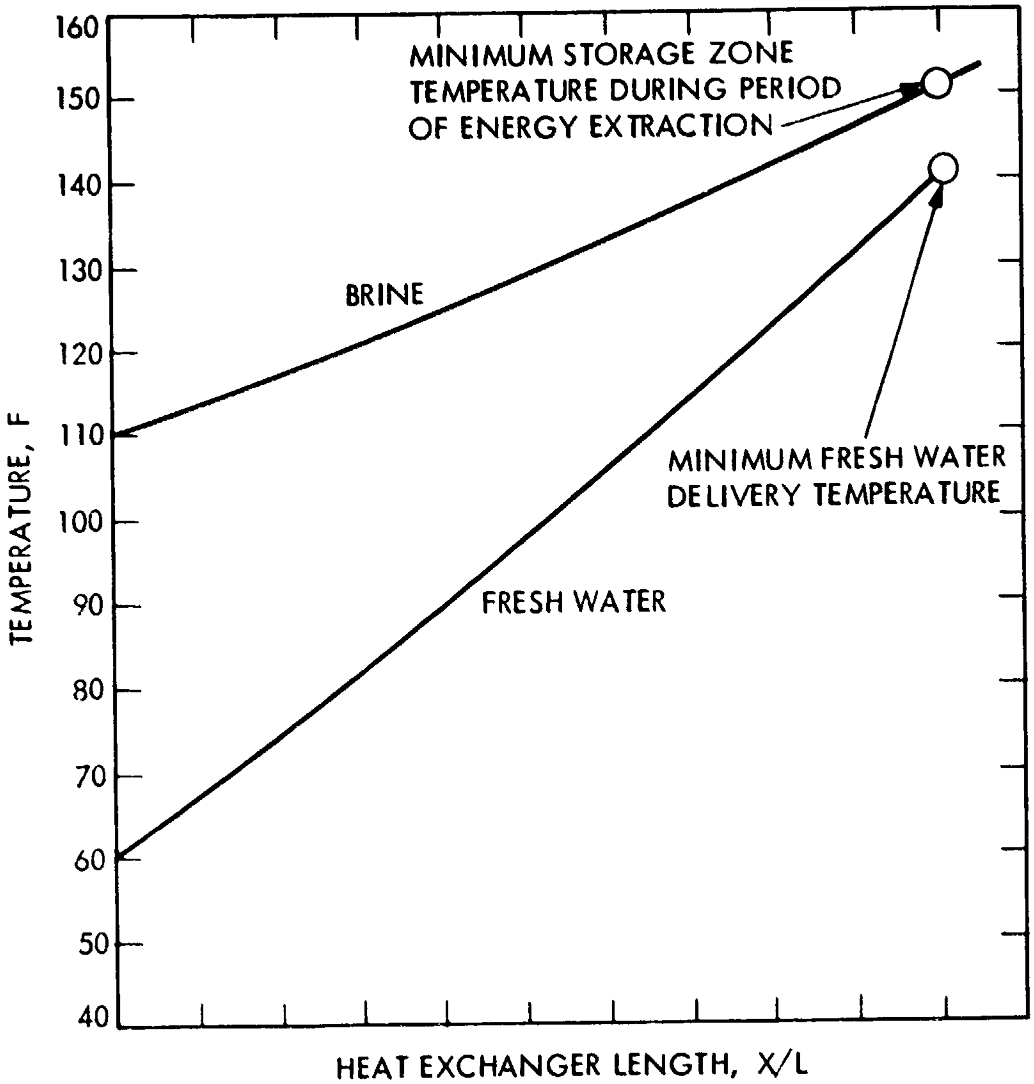

Figure 4-3. Example of Brine-Freshwater Heat Exchanger Characteristics at Minimum Solar Pond Storage-Zone Temperature

greater than the minimum brine delivery temperature are experienced during part of the month, but as more energy is being extracted from the storage zone than is being deposited, the storage-zone temperature decreases.

Temperature requirements were not specified nor are they appropriate for Cases 22 through 24. Although the primary criterion of interest in sizing the solar pond is to maximize the amount of electrical power generated, the brine temperature in the storage zone and the temperature of the surface zone affect the efficiency of thermal to electrical energy conversion. As such, constraints are imposed on the brine storage-zone temperature as discussed in the description of the analytical model (Ormat Turbine, Ltd., 1982).

4.1.2.4 Extraction Flow Rates. Extraction flow rates from the solar pond were based on the monthly energy requirements, the minimum storage-zone temperature experienced during energy extraction and the expected freshwater delivery flow rates.

For example, referring to Figure 4-3, the average monthly extraction flow rate from the solar pond would be based on the average monthly energy extraction rate and the 40°F temperature drop on the brine side of the heat exchanger. A reasonable balance between the brine flow rate and freshwater flow rate was maintained by increasing or decreasing the brine-side temperature drop as warranted. Maintenance of hydrodynamic stability within the solar pond as affected by the flow extraction was also considered in the flow-rate determination.

For Cases 1 through 10, a temperature drop of 40°F in the brine side of the heat exchanger was used in determining the extraction flow rates, whereas a 50°F brine-side temperature drop was used for Cases 11, 12, and 18 through 21. In Cases 13 and 14, a 60°F temperature drop was used on the brine side of the heat exchanger. A temperature drop of 25°F was used on the brine side of the brine/air heat exchangers in Cases 15 and 16, and a 35°F temperature drop was used on the brine side in Case 17.

As the solar pond storage-zone temperature increases from the minimum value (e.g., 10°F greater than the minimum required freshwater delivery temperature), the extraction flow rates can be reduced without sacrifice in system performance by allowing a larger temperature difference on the brine side of the heat exchanger. Alternately, the freshwater delivery temperature can be allowed to increase above the minimum temperature requirement.

4.1.2.5 Pond Transparency. The effect of pond transparency on energy penetration as a function of pond depth is significant (Ormat Turbines, Ltd., 1982). Because the quality of water is site-specific, many of the case studies were conducted for two water qualities, Types 2 and 3. The results obtained illustrate how pond sizing is affected by pond transparency. Type 2 is characteristic of ocean water treated to inhibit microbial growth and Type 3 is typical of continental shelf water. The water in solar ponds constructed in Israel is generally characterized as being between Types 2 and 3.

Pond Sizing. The determination of the pond area for Cases 1 through 21 was based on the average annual load requirement to be satisfied as output from the pond and the expected average annual storage-zone temperature. The average annual storage-zone temperature was not known a priori but could be estimated initially with reasonable accuracy on the basis of the minimum temperature that the storage zone was permitted to experience during periods of extraction and on the depth selected for the storage zone. The storage-zone depth affects the seasonal temperature extremes experienced in the storage zone, i.e., smaller temperature extremes experienced in the average annual storage-zone temperature are experienced with increasing depth of storage zone. The storage-zone depth for which seasonal temperature fluctuations are minimal depends on the seasonal variations of solar insolation and energy demands and is, therefore, site and application dependent.

After the initial selection of pond area was made, the behavior of the solar pond was computed using the monthly average energy demands as the energy output from the pond. If the minimum storage-zone temperature experienced during periods of energy extraction was greater than the allowable value, then either the storage-zone depth was reduced (resulting in larger seasonal temperature fluctuations) or a smaller pond area was used (resulting in a higher energy output per unit area of pond and a lower annual average pond temperature). Of course, a combination of both steps could also be taken.

On the other hand, if the minimum storage temperature experienced during periods of energy extraction was less than the allowable value, then either the storage-zone depth was increased or the area of the solar pond was made larger. The solar pond was considered to be sized in terms of pond area and depth when the minimum storage-zone temperature experienced during periods of energy extraction was equal to the minimum allowable temperature e.g., 150°F at a 140°F freshwater delivery temperature. The sizing process can be repeated several times until a reasonable size is obtained.

The adjustment of storage-zone depth has an impact on construction cost and pond operation and behavior. Variation of water quality (e.g., Type 2 or 3) was also considered in the sizing process. For Case 22, the solar pond depth was selected to minimize the seasonal variations in power output. For Cases 23 and 24, sizing is based on providing summer peaking power at the nominal 5-MWe level. Pond area is less than for the base-load case because the pond supplies a smaller amount of electric energy annually.

4.1.2.7 Model Variation. The Ormat Solar Pond Behaviour Model was used to predict the operation of the Ein Bokek solar pond near the Dead Sea, Israel. This 7,500-m^2 pond was completed during the late summer of 1978.

Two regimes of operation were modeled:

(1) Warming-up operation.

(2) Heat extraction.

Using local horizontal insolation values, local ambient temperatures, and a water transparency of Type 3 water together with the assumptions

mentioned above, storage-zone temperatures were obtained as shown in Figure 4-4 for the warm-up period. Close agreement between prediction and measurement is evident.

For the case of heat extraction, results of modeling the operation of the Ein Bokek solar pond during August to November 1981 are presented in Figure 4-5.

During this period, the pond, having an upper convective zone of 0.3 m, gradient zone of 1.1 m, and a storage zone of 1.0 m, was placed under a rigid operating schedule of energy extraction (see Figure 4-5). Again, there is good agreement between the predicted and measured temperatures. The Ormat Solar Pond Behaviour Model has been used to successfully determine the behavior of the solar pond built and operated at Yavne, Israel. It was also used in the feasibility study of the solar pond at the Salton Sea (Ormat Turbines, Ltd., 1982).

4.1.3 Results of Case Studies

4.1.3.1 Cases 1-10. Results of analyses performed for Cases 1-10 are summarized in Table 4-12. These cases represent space and water heating for a 120,000-ft^2 apartment complex. The effect of water type on required pond areas (with all other factors remaining constant) can be determined for different regions by comparing results of Cases 1.2 with 1.3, 2.3 with 2.4, 3.3 with 3.4, 8.2 with 8.3, and 9.1 with 9.2. It can be seen that pond transparency has a significant effect on the pond area.

The effect of minimum storage-zone temperature (minimum freshwater delivery temperature) on solar pond area (with all other factors remaining constant) can be determined by comparing results of Cases 1.1 with 1.3 and 2.2 with 2.3. It can be seen that the minimum storage-zone temperature has a significant effect on the pond sizing. The effect of storage-zone depth on the required pond area (all other factors remaining constant) can be determined by comparing Cases 3.1 with 3.4 and 4.1 with 4.2. It can be seen that the solar pond area is relatively insensitive to the storage-zone depth for the cases analyzed.

From Table 4-12, it can be seen that the maximum storage-zone temperature achieved in Case 10 without energy extraction is approximately 57°C.

Monthly extraction rates for Cases 1 through 10 are given in Table 4-13. These flow rates are based on a 10°F temperature drop across the brine-freshwater heat exchanger and a 40°F temperature drop on the brine side of the heat exchanger. Reductions from these flow rates can be realized when the storage-zone temperature is greater than the minimum required brine temperature such that the minimum freshwater temperature is provided on a year-around basis. Alternatively, if the extraction flow rates are not reduced from the values given in Table 4-13, the freshwater temperature will be greater than the minimum required value when the storage-zone brine temperature exceeds the minimum required value.

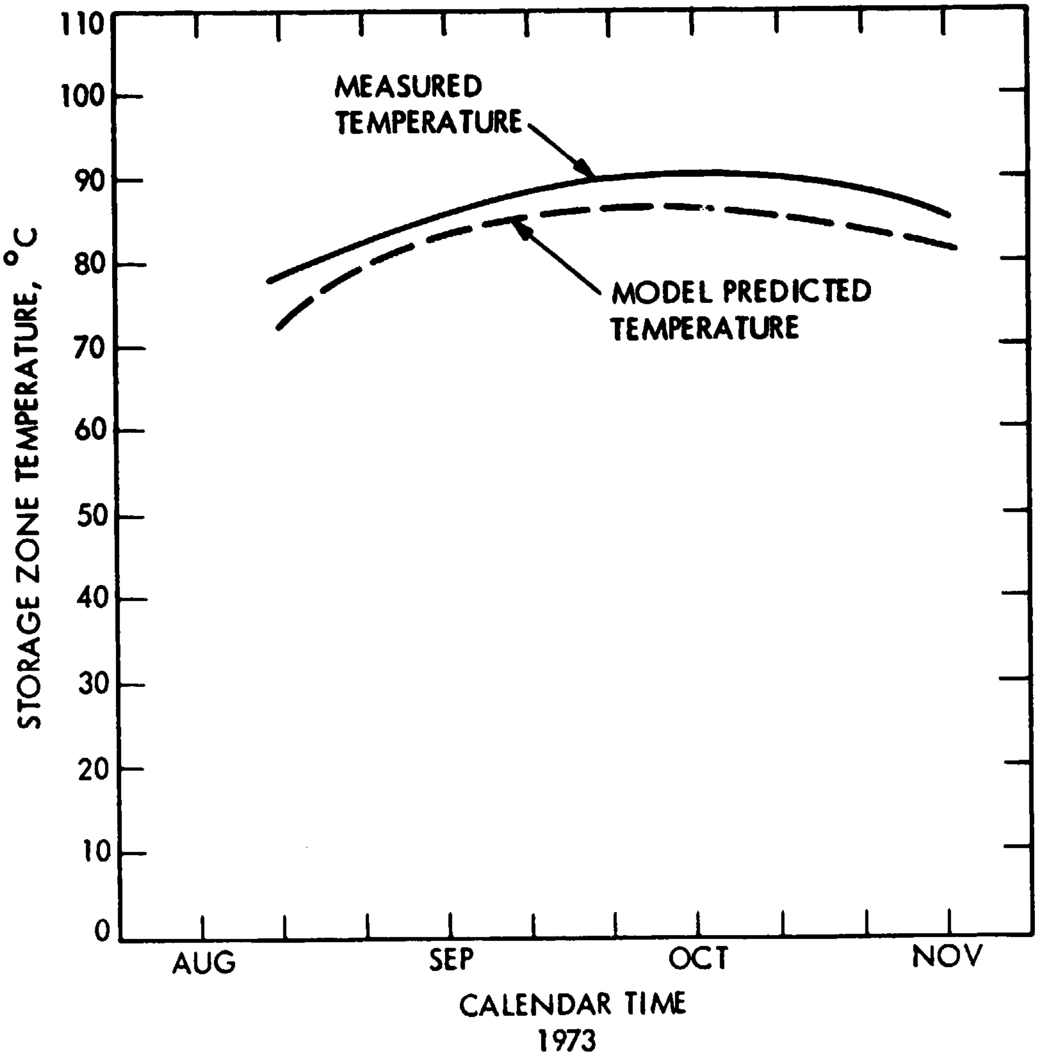

Figure 4-4. Comparison Between Ormat Model Prediction and Actual Measurement of Storage-Zone Temperature During the Warm-up Period at the Ein Bokek Solar Pond, Israel

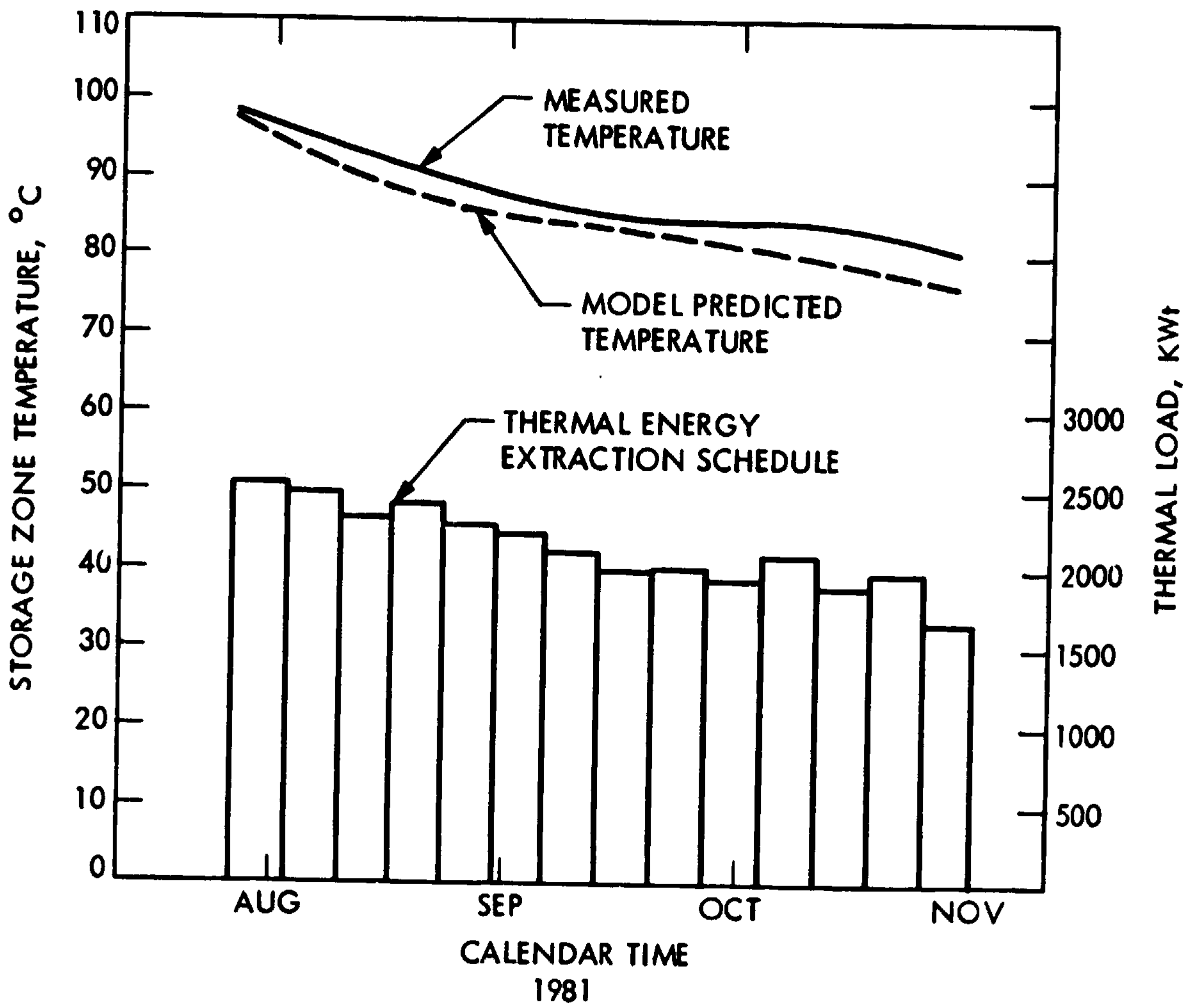

Figure 4-5. Comparison Between Ormat Model Prediction and Actual Measurement of the Storage-Zone Temperature During Energy Extraction at the Ein Bokek Solar Pond, Israel

Table 4-12. Summary of Results for Cases 1 Through 10 - Space and Water Heating

Case No.	Location/Region	Yearly Average Load/Month kW	Maximum to Minimum Load Ratio	Yearly Average Insolation W/m^2	Water Type	Storage Zone Depth m	Pond Surface Area m^2	Minimum Storage-Zone Temperature °C
1.1	Boston, Mass./	174,418	6.3	145	2	3	21,400	65.6
1.2	Atlantic Northeast	174,418	6.3	145	3	3	22,100	54.4
1.3		174,418	6.3	145	2	3	11,200	54.4
2.1	Nashville, Tenn./	134,225	5.2	167	2	3.5	7,100	65.6
2.2	Tennessee Valley	134,225	5.2	167	3	3	14,200	65.6
2.3		134,225	5.2	167	3	3	8,500	54.4
2.4		134,225	5.2	167	2	3	5,500	54.4
3.1	Atlanta, Ga./	121,680	4.6	177	2	3	5,400	65.6
3.2	Gulf Coast	121,680	4.6	177	3	3	8,500	54.4
3.3		121,680	4.6	177	3	3.5	9,000	65.6
3.4		121,680	4.6	177	2	3.5	4,900	65.6
4.1	Madison, Wis./	218,433	7.9	156	2	3	21,800	65.6
4.2	Great Lakes	218,433	7.9	156	2	3.5	19,800	65.6
5.1	Bismarck, N.Dak./ Black Hills	189,646	6.8	164	2	3.5	18,200	65.6
6.1	Fort Worth, Tex./	106,786	4.2	194	2	2.5	3,900	65.6
6.2	Red River	106,786	4.2	194	3	3.5	5,700	65.6
7.1	Seattle, Wash./ Red River	165,907	6.0	138	2	3.5	29,900	65.6
8.1	Salt Lake City, Utah/	181,964	6.8	211	2	3	7,400	65.6
8.2	Salt Lake	181,964	6.8	211	3	3.5	10,700	65.6
8.3		181,964	6.8	211	2	3.5	7,000	65.6
9.1	Phoenix, Ariz./	89,473	3.0	246	2	3.5	2,100	65.6
9.2	Southwest	89,473	3.0	246	3	3.5	3,000	65.6
10.1	Fairbanks, Alas./ Alaska	356,492	7.6	101	2	3.5	a	b

[a]No operating solar pond feasible.

[b]Minimum storage-zone temperature of 31°C achieved without energy extraction.
Maximum storage-zone temperature of 57°C achieved without energy extraction.

Table 4-13. Summary of Extraction Flow Rates For Cases 1 Through 10

Month	Extraction Rate, m^3/h									
	Case No									
	1	2	3	4	5	6	7	8	9	10
January	12.7	11.2	9.8	18.1	15.4	9.1	11.2	14.4	6.9	-
February	10.9	9.5	8.4	15.6	13.0	7.2	9.2	10.8	5.5	-
March	10.2	7.9	7.1	13.7	11.6	5.9	9.3	10.8	4.4	-
April	9.2	4.4	4.0	8.6	7.4	3.4	7.6	7.4	3.1	-
May	5.4	2.8	2.5	5.4	4.8	2.3	5.5	4.8	2.3	-
June	2.5	2.1	2.1	2.8	3.0	2.1	3.8	3.1	2.1	-
July	2.1	2.1	2.1	2.3	2.3	2.1	3.0	2.1	2.1	-
August	2.1	2.1	2.1	2.5	2.4	2.1	3.0	2.1	2.1	-
September	3.7	2.4	2.4	4.1	4.8	2.3	4.1	3.4	2.3	-
October	5.7	4.4	4.0	7.5	6.7	3.1	6.7	6.7	2.7	-
November	9.5	7.6	6.8	12.0	10.5	5.5	8.9	10.6	4.4	-
December	13.6	10.5	9.5	16.4	13.7	8.1	10.5	13.7	6.5	-

4.1.3.2 Cases 11, 12 and 18 through 21. Table 4-14 summarizes the results of analyses which were conducted for Cases 11, 12, and 18 through 21. Because of the relatively large energy requirements (in comparison with the same regions in Case 1 through 10 all of the ponds were sized for a minimum brine storage-zone temperature of 54.4°C (130°F). It can be seen from Table 4-14 that there is a significant influence of water type on the pond area, as was true with Cases 1 through 9. The brine extraction flow rate shown in Table 4-14 is based on a temperature difference of 10°F across the brine-freshwater heat exchanger, as was previously discussed and a 27.8°C (50°F) temperature drop on the brine side of the heat exchanger.

Additional results for these cases which illustrate the brine storage-zone temperature levels during the year are given in Table 4-15. These results are given for the pond areas shown in Table 4-14 water Type 3.

Table 4-14. Summary of Results for Cases 11, 12, 18 through 21 - Poultry Dressing Plant

Case No.	Location/Region	Yearly Average Load/Month kW	Maximum to Minimum Load Ratio	Yearly Average Insolation W/m^2	Water Type	Storage Zone Depth m	Pond Surface Area m^2	Minimum Storage Zone Temperature °C	Brine Extraction Flow Rate, m^3/h
11.1	Boston, Mass./	912,275	1	145	2	3.5	52,800	54.4	31.1
11.2	Atlantic Northeast	912,275	1	145	3	3.5	104,000	54.4	31.1
12.1	Phoenix, Ariz./	912,275	1	246	2	3.5	15,400	54.4	31.1
12.2	Southwest	912,275	1	246	3	3.5	21,000	54.4	31.1
18.1	Fort Worth, Tex./	912,275	1	194	2	3.5	23,000	54.4	31.1
18.2	Red River	912,275	1	194	3	3.5	31,100	54.4	31.1
19.1	Madison, Wis./	912,275	1	156	2	3.5	46,300	54.4	31.1
19.2	Great Lakes	912,275	1	156	3	3.5	86,100	54.4	31.1
20.1	Seattle, Wash./	912,275	1	138	2	3.5	62,100	54.4	31.1
20.2	Pacific Northwest	912,275	1	138	3	3.5	132,000	54.4	31.1
21.1	Atlanta, Ga./	912,275	1	177	2	3.5	26,500	54.4	31.1
21.2	Gulf Coast	912,275	1	177	3	3.5	38,600	54.4	31.1

Table 4-15. Brine Temperature Levels During the Year

Temperature, °C	Case No.[a] 11	12	18	19	20	21
	Percent Time of Year Above Given Temperature					
54.4	100	100	100	100	100	100
60.0	73	65	62	62	62	59
65.6	43	51	41	46	45	35
71.1	0	0	19	24	30	0

[a]Using same pond areas as in Table 4-14, Type 3 water.

It can be seen that the third-choice minimum freshwater temperature (48.9°C or 120°F) is provided 100%. In fact, the brine temperature exceeds 60.0°C (140°F) for approximately 60% or more of the year for all of the cases (59% for Case 21) so that the second-choice minimum freshwater temperature (54.4°C or 130°F) could be provided for 60% or more of the time.

Similarly, it can be seen from Table 4-15 that the first choice freshwater temperature (60.0°C or 140°F) can be achieved from 35 to 50% of the time in that the brine storage-zone temperature exceeds 65.6°C (150°F) for this amount of time, depending on the specific case. Thus, a pond sized to provide the third-choice minimum freshwater delivery temperature for 100% of the time can also satisfy a more stringent minimum freshwater temperature requirement for a significant portion of the time using suitable energy extraction techniques.

4.1.3.3 Case 13. Case 13 is for a seasonal water heating canning plant in Stockton, California. Pond sizing is shown in Table 4-16 which satisfies the energy requirements for a minimum freshwater delivery temperature of 65.6°C (150°F), corresponding to a minimum storage-zone temperature of 71.1°C (160°F), for both water Types 2 and 3, and for a minimum freshwater delivery temperature of 76.7°C (170°F), corresponding to a minimum storage-zone temperature of 82.2°C (180°F). The brine extraction flow rate of 99 m^3/h is based on a temperature drop of 33.3°C (60°F) on the brine side of the heat exchanger.

4.1.3.4 Case 14. Case 14 is for a frozen foods process application in Phoenix, Arizona, with a constant energy demand throughout the year. Pond sizing is shown in Table 4-16 for a minimum freshwater temperature of 65.6°C (150°F), corresponding to a minimum storage temperature of 71.1°C (160°F), for both water Types 2 and 3; and for a minimum freshwater delivery temperature of 77.0°C (171°F), corresponding to a minimum storage-zone temperature of 82.6°C (181°F), for water Type 3. The brine extraction flow rate is based on a 33.3°C (60°F) temperature drop on the brine side of the heat exchanger.

4.1.3.5 Case 15 and 16. Cases 15 and 16 are for seasonal crop drying applications. Pond sizing results are shown in Table 4-16 which satisfy the minimum brine temperature requirements during the period of energy extraction. Results are given for water Types 2 and 3, and the extraction flow rate is based on a 13.9°C (25°F) temperature drop on the brine side of the heat exchanger.

4.1.3.6 Case 17. Case 17 represents a farmhouse heating and crop drying application in Chicago, Illinois. The pond was sized such that the brine storage-zone temperature was never lower than the first choice minimum brine temperature on a monthly basis. The brine extraction rate for Case 17 corresponds to 40 g/m.

4.1.3.7 Case 22-24. Base-load and peak-load electric power generation are studied in Cases 22, 23, 24 and the results are summarized in Table 4-17.

Table 4-17 identifies the applications, the mode of energy extraction, pond area, pond depth (total depth, including the upper convective zone, middle non-convective zone, and lower storage zone), and water type.

In Case 22.1, the solar pond was sized to produce 5-MW gross, or 3.75-MW net. A utilization factor of 80% at the rated power level was assumed. Thus the average annual output is 26.3 million kWh, as shown in Table 4-18 along with the average monthly power output.

Steps were taken in order to minimize the effects of seasonal variation on the SPPP output. First, a 3.5-m deep storage zone was used. In addition, the energy was extracted from the storage zone at a rate which maintains the temperature of the storage zone at

$$T(^{o}C) = 64 + 10 \sin \left(\frac{2\ (D-90)}{365}\right)$$

where D is the number of days measured from the vernal equinox.

Table 4-19 presents the seasonal performance of a SPPP at the Great Salt Lake. Here "summer" refers to the 3 months with the most output, i.e., July, August, September, while "winter" refers to the 3 months with the least output, i.e., December, January, February.

In Cases 23 and 24, summer peaking load is studied at Great Salt Lake and Detroit, respectively. Two alternatives are given for the 5-MW

Table 4-16. Summary of Results for Cases 13 Through 17

Case No.	Location/Region	Application	Yearly Average Load/Month kW	Yearly Average Insolation W/m^2	Water Type	Storage-Zone Depth m	Pond Surface Area m^2	Minimum Storage-Zone Temperature °C	Brine Extraction Flow Rate, m^3/n
13.1	Stockton, Calif./	Canning Plant	865,659	217	2	3.5	26,000	71.1[a]	99[a]
13.2	Southwest	Seasonal	865,659	217	3	3.5	37,900	71.1[a]	99[a]
13.3		Water Heating	865,659	217	3	3.5	51,800	82.2[a]	99[a]
14.1	Phoenix, Ariz./	Frozen Foods	868,976	246	2	3.5	18,700	71.1	24.6
14.2	Southwest	Plant	868,976	246	3	3.5	28,400	71.1	24.6
14.3			868,976	246	3	3.5	38,800	82.6	24.6
15.1	Des Moines, Iowa/ Great Lakes	Seasonal Crop Drying	868,767	172	2	3.5	24,900	46.1, 36.1, 30.0[b]	241[b]
15.2		Seasonal Crop Drying	868,767	172	3	3.5	35,300	46.1, 36.1, 30.0	241[b]
16.1	Fort Worth, Tex./ Red River	Seasonal Crop Drying	868,767 868,767	194 194	2	3.5	24,800	52.8, 46.1, 41.7[b]	241[b]
16.2			868,767	194	3	3.5	32,300	52.8, 46.1, 41.7[b]	241[b]
17.1	Chicago, Ill./ Great Lakes	Farmhouse Heating and Crop Drying	77,968	160	3	3.5	7,000	varying[c] (First Choice)	0.0025

[a]The temperature and brine extraction rate are relevant for the period July 16 - October 15, during which time the required energy is being extracted.

[b]These temperatures and brine extraction rate are relevant for the months October, November, and December, during which time the required energy is being extracted. The brine extraction flow rate is constant during this period.

[c]See Figure 4-2.

Table 4-17. Summary of Electric Power Generation Cases 22 Through 24.

Case No.	Location/Region	Case Description	Pond Area, km^2 (acres)	Total Pond Depth, m	Water Type
22.1	Great Salt Lake/ Salt Lake Region	5-MW year-around base-load	1.97 (486)	5.05	3
23.1	Great Salt Lake/ Salt Lake Region	5-MW constant summer peaking-	0.68 (169)	5.05	3
23.2	Great Salt Lake/ Salt Lake Region	5-MW summer peak-load	0.66 (163)	5.05	3
24.1	Detroit/Great Lakes Region	5-MW constant peaking-load	1.62 (400)	5.05	3
24.2	Detroit/Great Lakes Region	5-MW summer peak-load	1.28 (315)	5.05	3

summer peaking loads in both cases. In alternatives 23.1 and 24.1, a constant 5-MW (gross) or 3.75-MW (net), 24 hours a day, while during the remaining months of the year, no energy is extracted from the pond. However, in alternatives 23.2 and 24.2, the nominal 5-MW summer peaking load is provided for only a portion of the 24-hour day. During the rest of the year, no energy is extracted. Table 4-20 and Figure 4-6 summarize these results.

If base-load operation is compared to peaking operation in Cases 22 and 23, it can be seen from Table 4-17 that in the peaking case, less pond area is needed to provide the power requirement. However, as Table 4-21 shows, the base-load plant operates at a higher pond efficiency, i.e., a greater fraction of heat can be extracted in the base load mode than in the peaking mode.

4.2 ENERGY DISTRIBUTION/CONVERSION SUBSYSTEMS

4.2.1 Distribution/Conversion Subsystem Layout

The design of energy distribution subsystems depends to a large extent on the specific applications. Generally, heat extraction from solar ponds can be done with in-pond or out-of-pond heat exchangers. But the trend is to favor the latter because of easier maintenance and less corrosion problems. To limit the corrosion effects of hot brine on the heat transport equipment, it is desirable to locate the brine-to-transport-fluid heat exchanger as close to the pond as possible. It is also desirable to minimize the length of heat transport pipelines, wherever possible, such that heat loss

Table 4-18. Monthly Performance of Base Load SPPP at the Great Salt Lake (Case 22.1)

Month	Net Electrical Power Output, MW	Net Electrical Energy 10^6kWh
January	3.11	1.85
February	3.14	1.69
March	3.35	1.99
April	3.63	2.09
May	4.16	2.48
June	4.22	2.43
July	4.24	2.52
August	4.32	2.57
September	4.28	2.47
October	3.86	2.30
November	3.43	1.98
December	3.26	1.94
Annual Average	3.75[a]	Annual Total 26.3[a]

[a]Analysis based on water type No. 3.

Table 4-19. Seasonal Performance of a SPPP Located at the Great Salt Lake

Performance Parameter	Power Ratio
Summer/Winter Output	1.35
Winter/Yearly Output	0.85
Summer/Yearly Output	1.14

Table 4-20. Characteristics of Summer Peaking SPPP (Cases 23 and 24)

Case No.	Location/Region	Case Description	Peak Power MW(gross)	Peak Power MW(net)	Average Summer Peak MW(gross)	Average Summer Peak MW(net)
23.1	Great Salt Lake/ Salt Lake	5-MW constant summer peaking Load	5	3.75	5	3.75
23.2	Great Salt Lake/ Salt Lake	5-MW variable summer peaking load	5	3.75	3.33	2.49
24.1	Detroit/ Great Lakes	5-MW constant summer peaking load	5	3.75	5	3.75
24.2	Detroit/ Great Lakes	5-MW variable summer peaking load	5	3.75	3.30	2.48

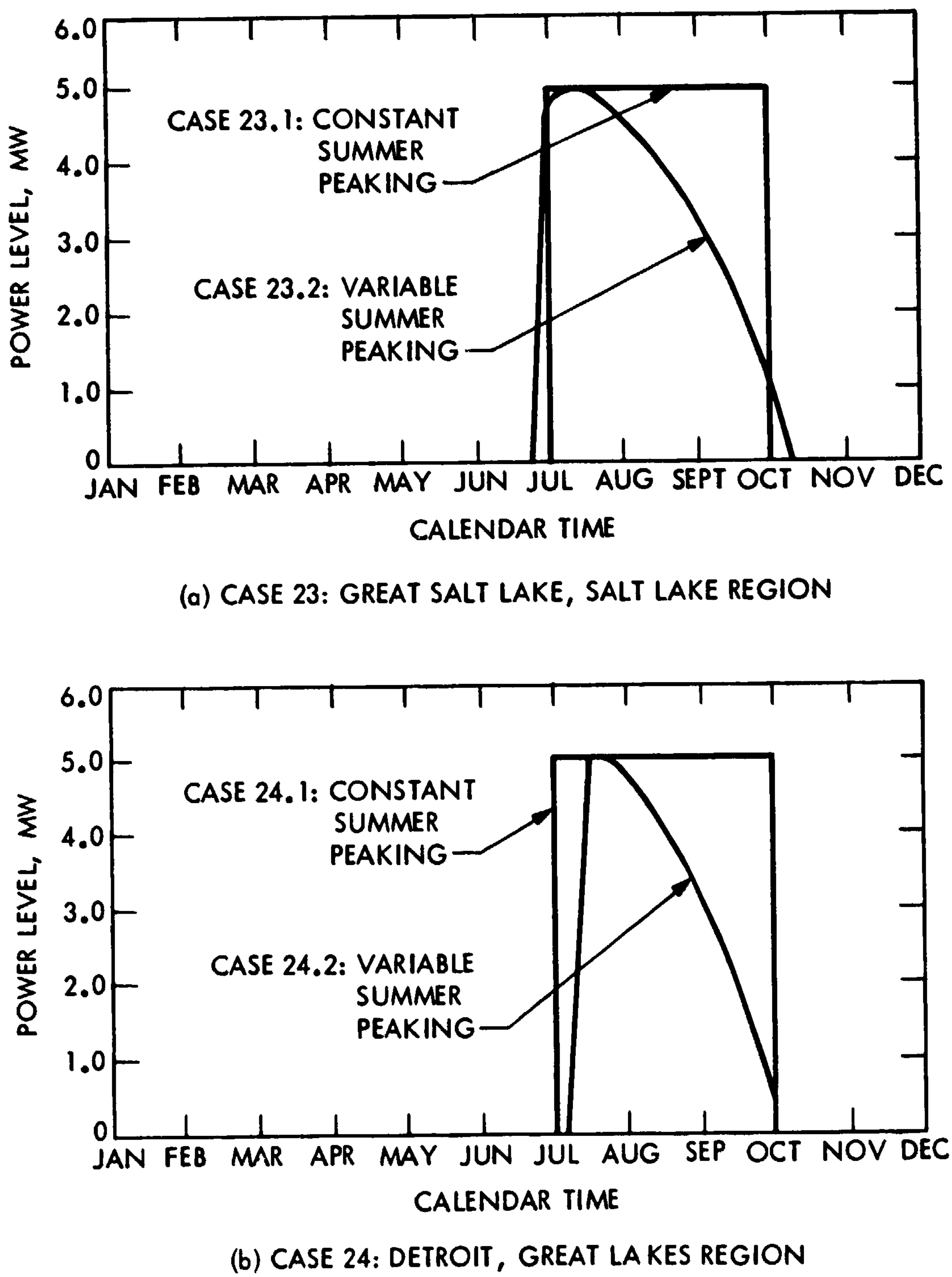

Figure 4-6. Peak-Load Electric Power Generation/Cases 23 and 24, Power Output

Table 4-21. Comparison of Base-Load (Case 22) and Peak-Load (Case 23) Pond Efficiencies

Heat Component	Base Load	Peak Load
Losses to the atmosphere	85%	87%
Losses to the ground	2%	2%
Extracted heat	13%	11%

is reduced in the transport process. Some examples of energy distribution/conversion subsystem layouts are:

(1) Space and Water Heating for Low-Rise Apartment Complexes. Figure 4-7 shows a schematic layout for this application. Each apartment unit has a fan coil unit to transfer thermal energy from the transport fluid to air for space heating, and a water heater to produce domestic hot water.

(2) Space and Water Heating for a 100-House District. Figure 4-8 shows a possible arrangement for the energy distribution subsystem. Each house can have a fan coil unit and/or a water heater similar to what is shown in Figure 4-7.

(3) Multiple Farm Use. Brine-water and brine-air heat exchangers are needed to transfer thermal energy from a solar pond for grain drying, farmhouse and animal-shelter heating, and various hot water services. Figure 4-9 shows an example for such an application.

(4) Electric Power Generation. An organic Rankine power conversion system is shown in Figure 4-10, with the various components identified. This is typical of the arrangement currently under design for the Salton Sea solar pond power plant in Southern California.

(5) Cooling and Refrigeration. Cooling demands coincide with high-insolation seasons, and solar ponds can potentially be utilized for cooling and refrigeration purposes. Several methods can be employed to effect cooling and refrigeration with solar ponds; e.g., absorption, vapor-ejector driven, and Rankine cycle-vapor compression systems. However, the coefficients of performance (COP) for these systems are low when source temperature is low, and further R&D is required to improve the performance of these systems. Figure 4-11 shows an absorption air conditioning and refrigeration system using solar ponds as a heat source. Absorption systems using lithium bromide-water or ammonia-water as working fluid are

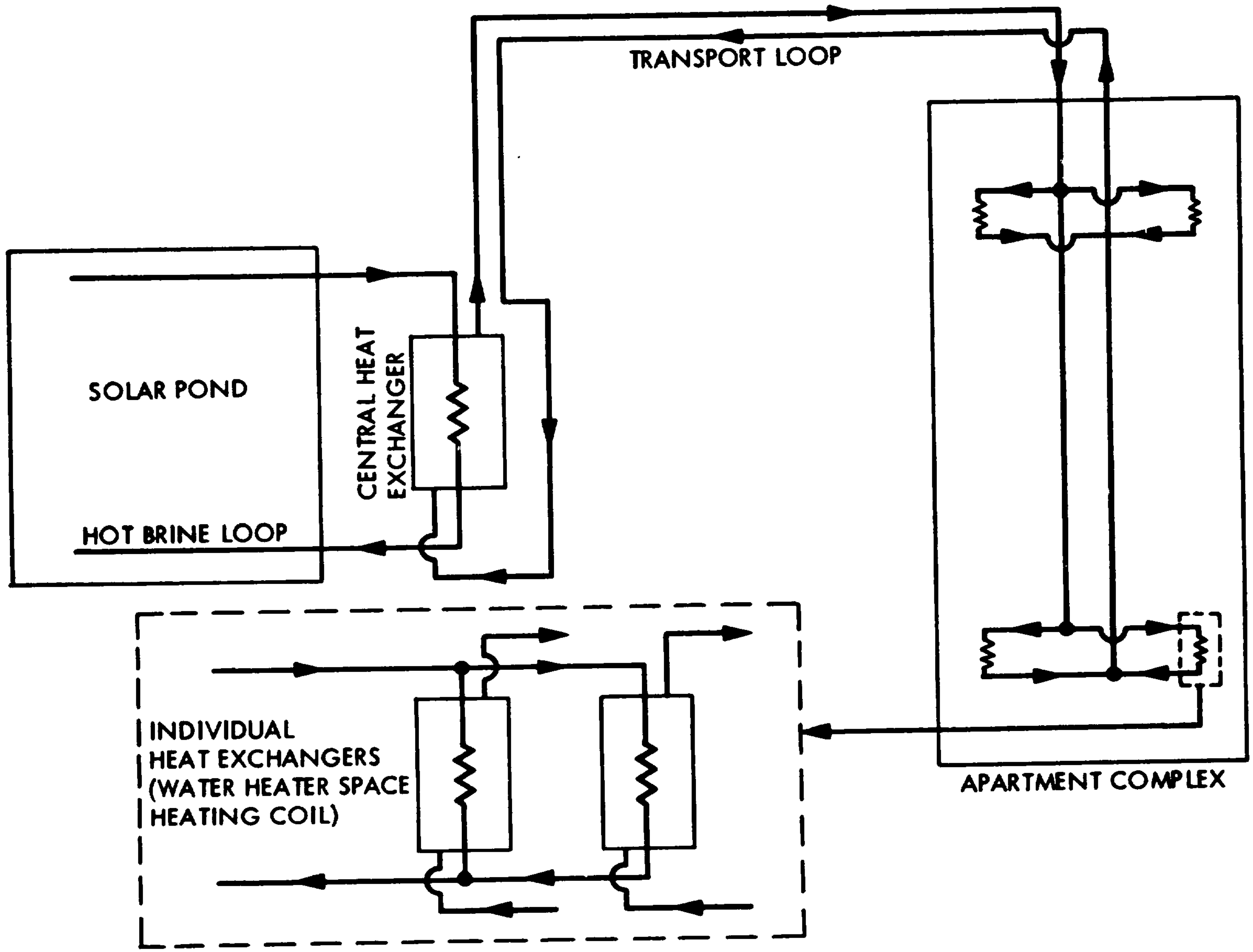

Figure 4-7. Energy Distribution Subsystem for a Low-Rise Apartment Complex

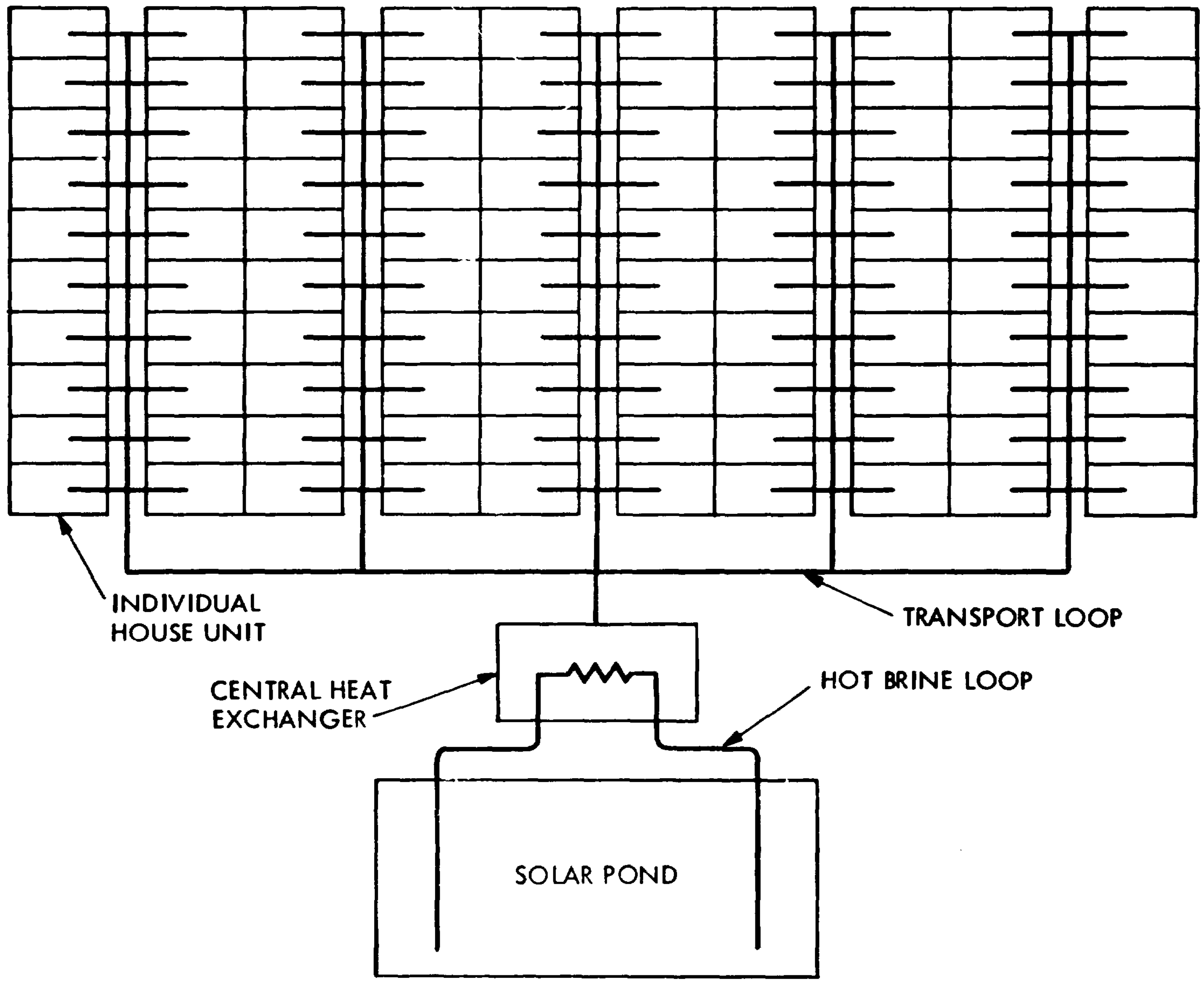

Figure 4-8. A 100-House District Heating System Layout

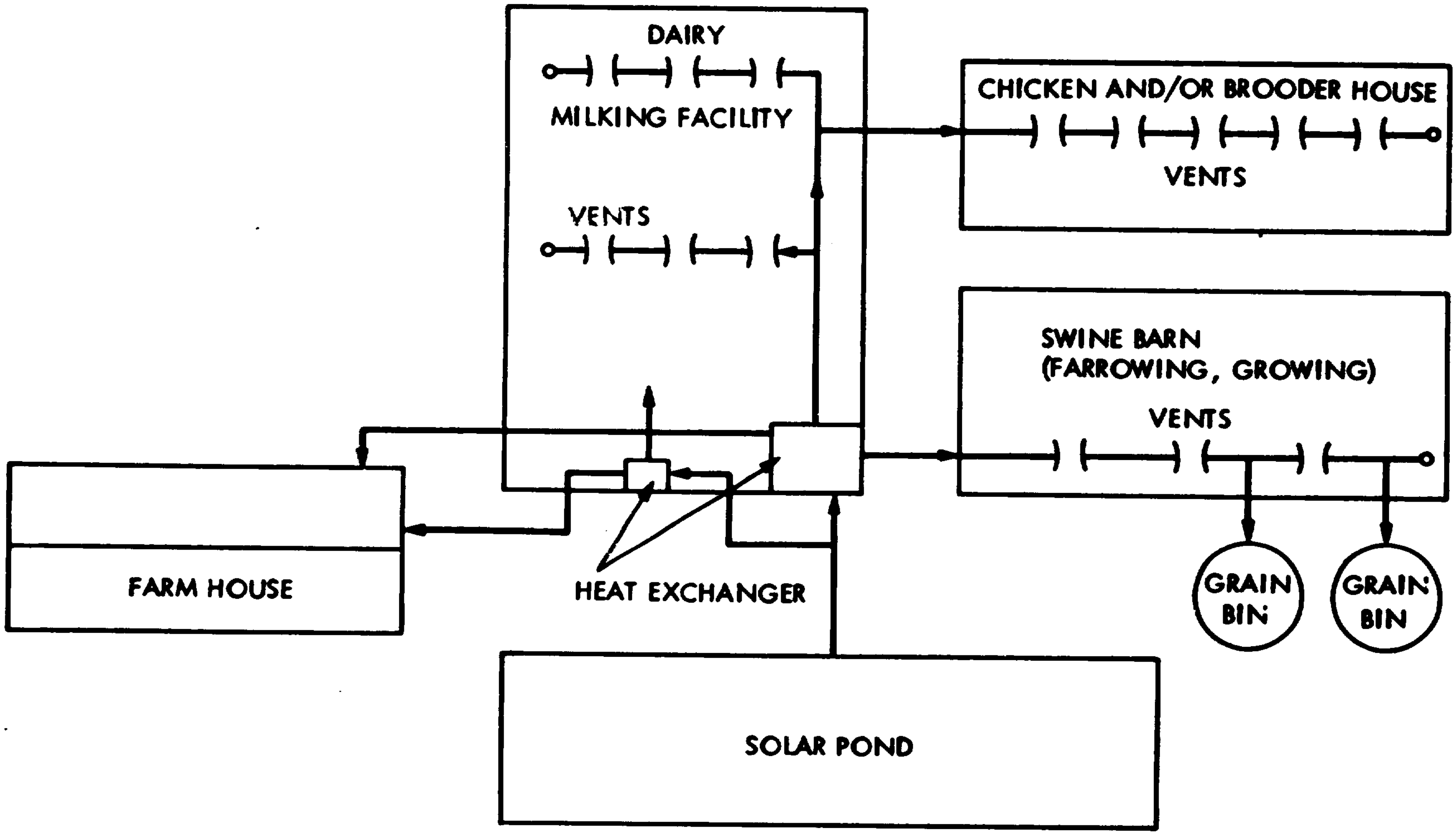

Figure 4-9. Multiple Use of a Solar Pond on a Farm

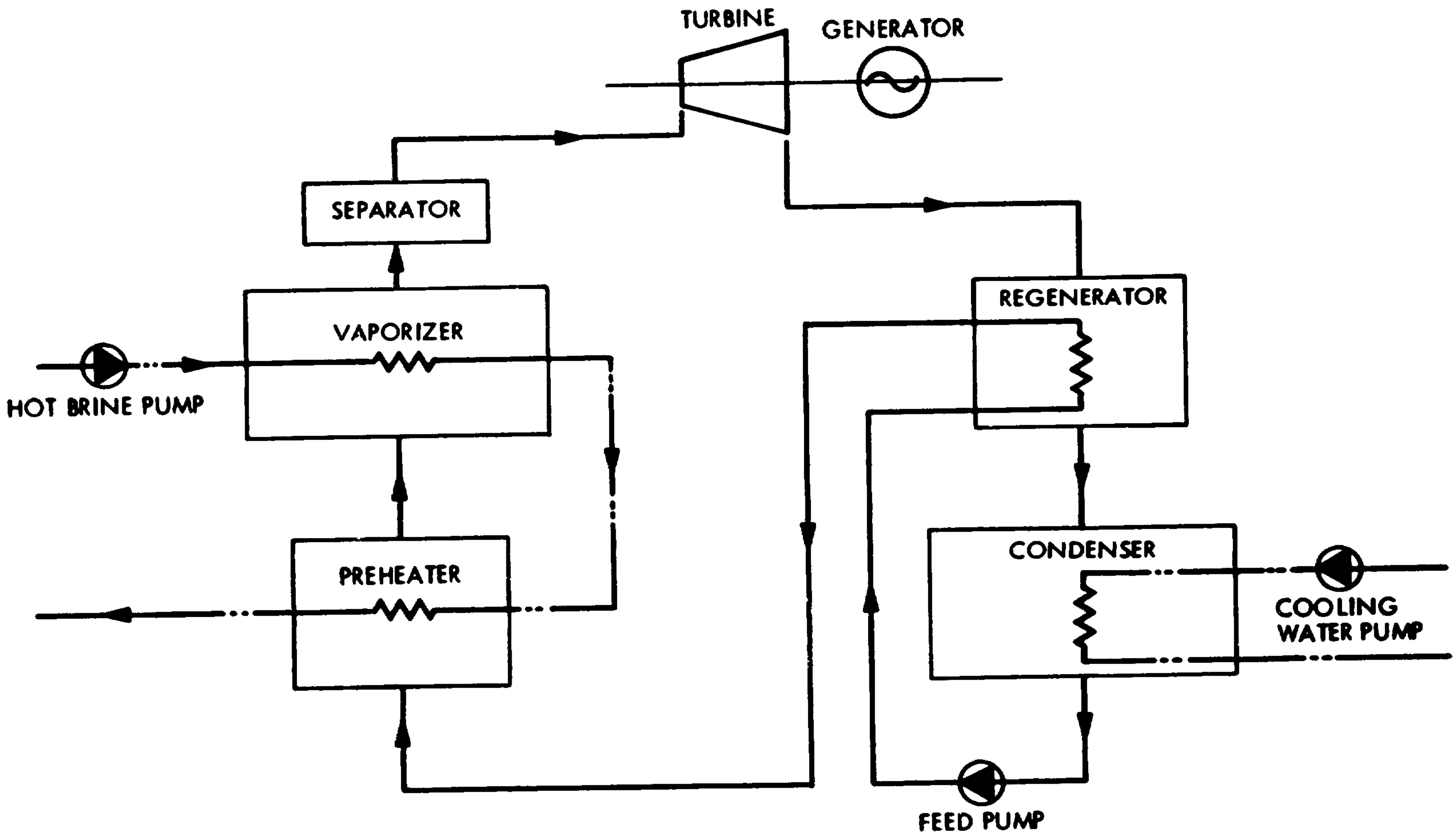

Figure 4-10. Electric Power Generating Subsystem

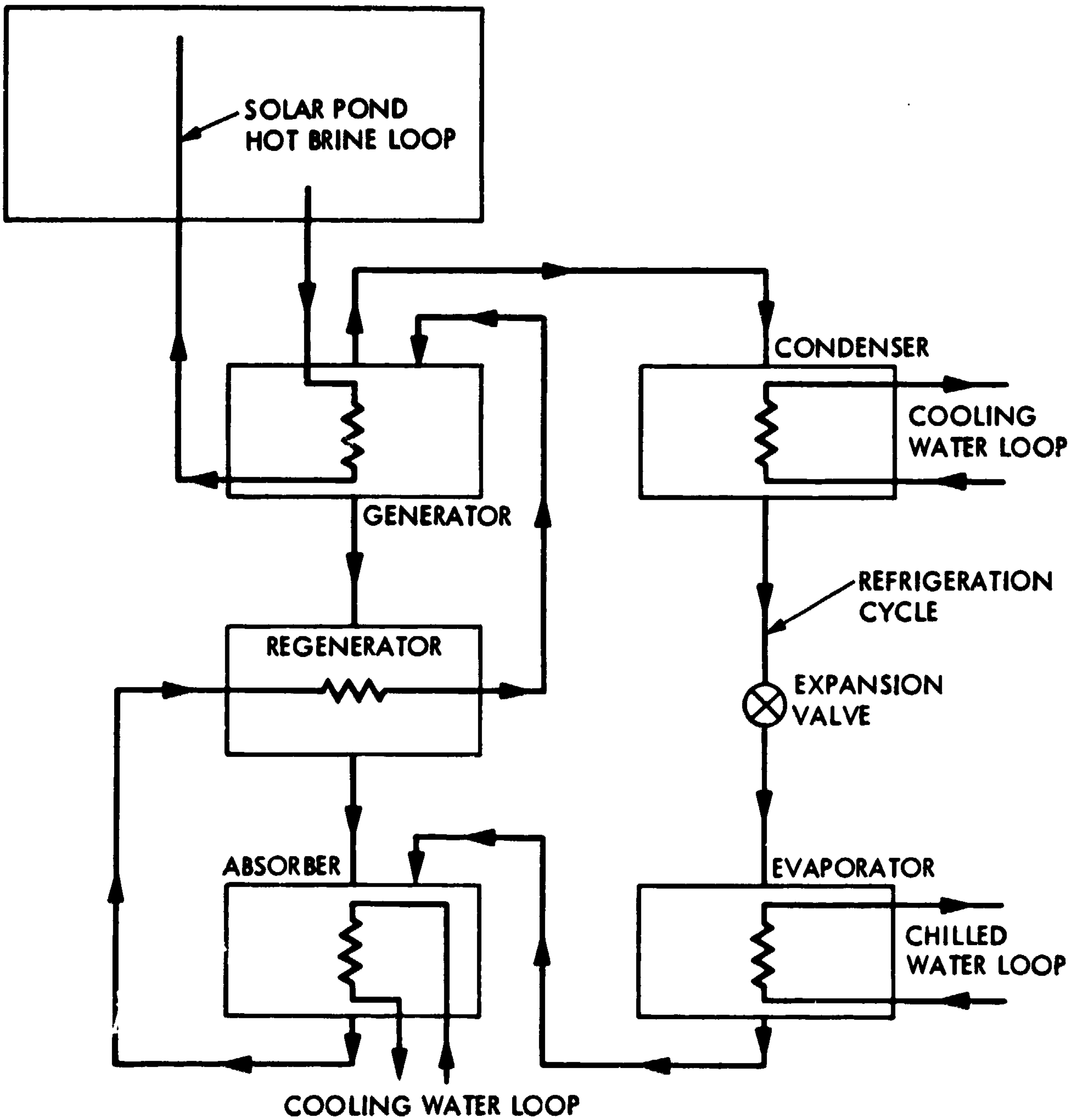

Figure 4-11. A Solar Pond Absorption Refrigeration System

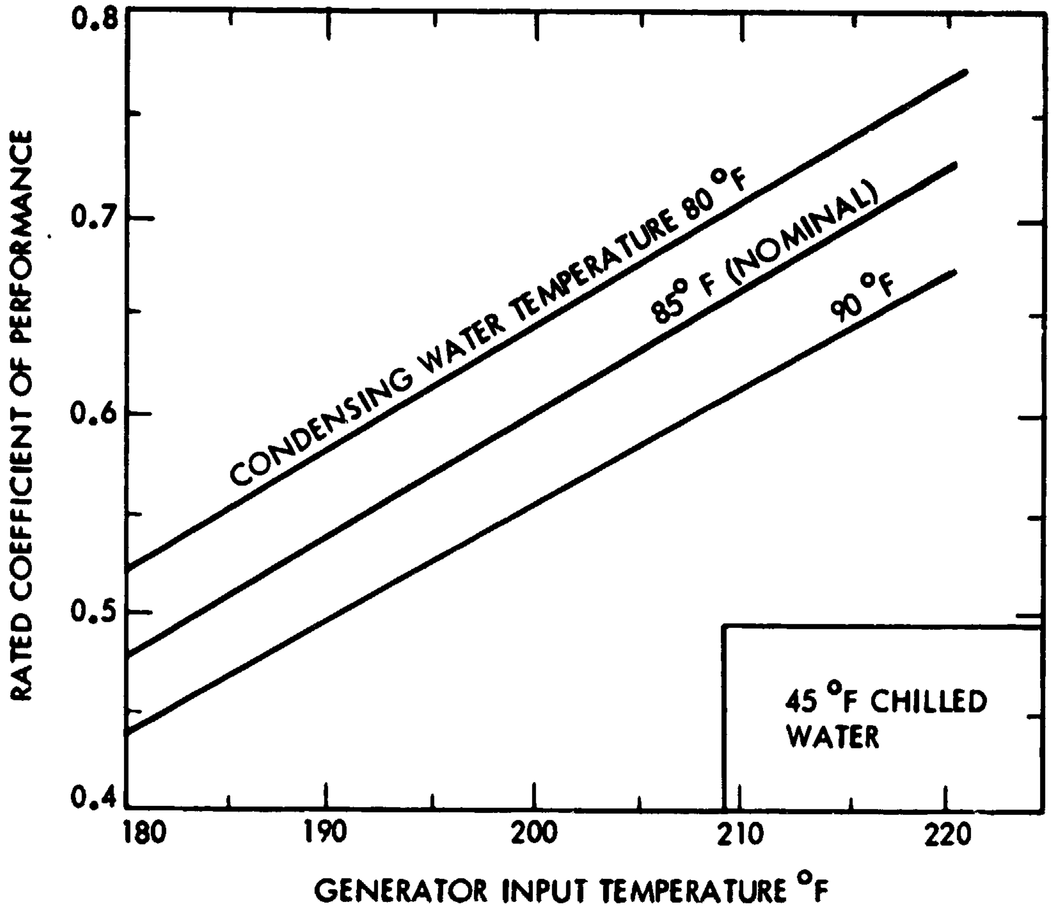

Figure 4-12. Rated COP for ARKLA 1200 LiBr-H_2O System

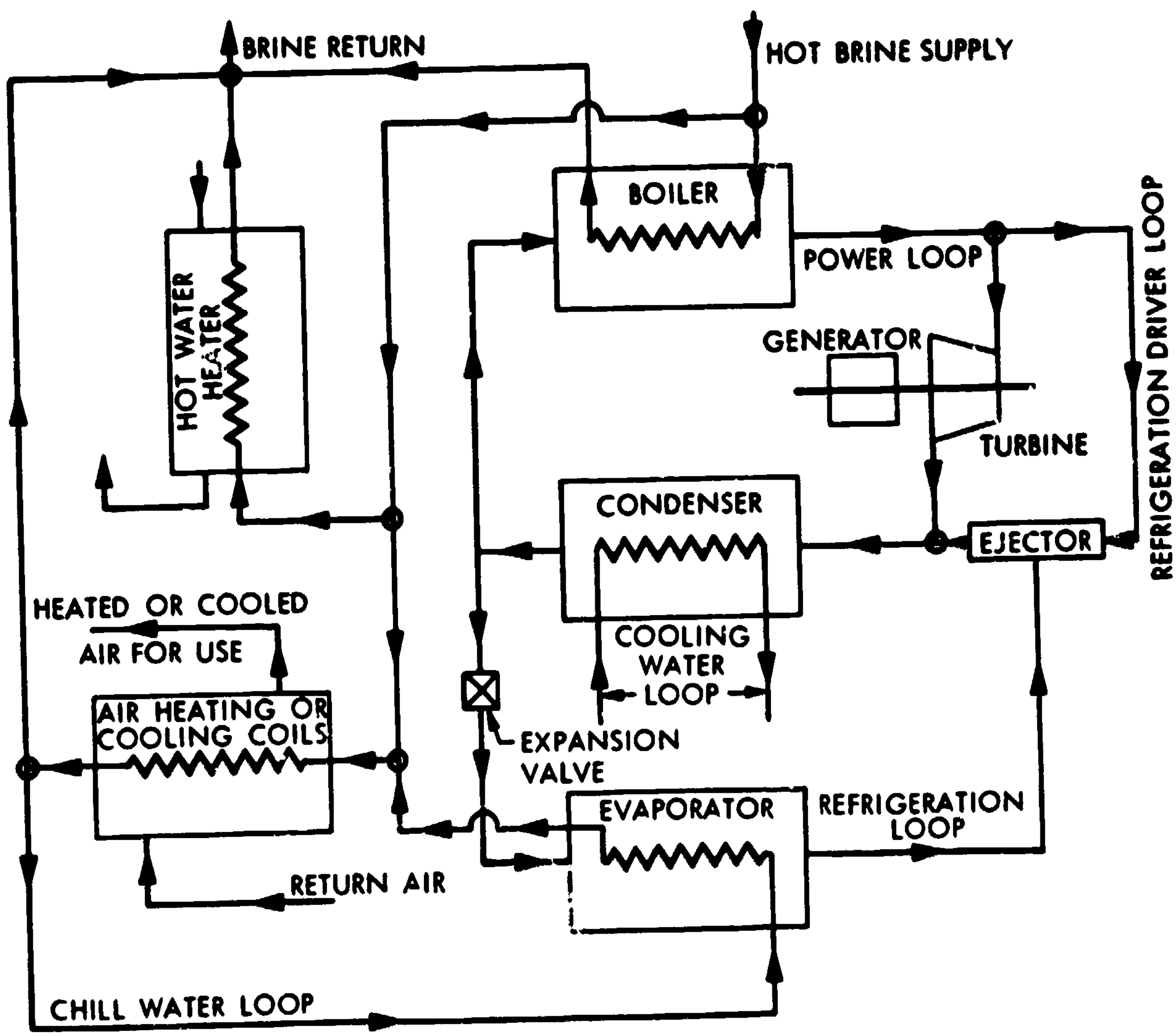

Figure 4-13. Solar Pond Total Energy Systems: Electricity, Heating, and Cooling

commercially available. To give a general idea of the performance of these systems, Figure 4-12 shows the COP of an ARKLA lithium bromide-water system as a function of heat source temperature for several condenser temperatures.

(6) Solar Pond Total Energy System. An integrated solar pond system generating thermal and electrical energy to serve multiple purposes under varied design schedules is a possibility and may have certain economic advantages. Figure 4-13 gives an example for such an arrangement.

4.2.2 Cost Data for Selected Distribution Subsystems

Component cost data for a number of energy distribution subsystems were gathered via a telephone survey of several vendors/manufacturers:

- Heat exchanger-related information:

  Young Radiator Company
  American Standard
  Alfa-Laval
  A. O. Smith
  Henry Vogt Machine Company
  Paul Mueller Company

- Pump-related information:

  Peerless Pump
  Nagle Pumps, Inc.
  Pacific Pumps
  Bingham-Williamette Company
  Hayward Tylar
  Peabody Howay, Inc.
  Layne & Bowler, Inc.

- Pipe-related and miscellaneous information:

  Johns-Mansville
  State Pipe & Supply Company
  Hope Corguard, Inc.
  Ershigs, Inc.
  Mueller Company
  A. O. Smith-Inland, Inc.

In addition, piping network cost data were also obtained from Biddle, et al, (1980), and Lesse, et al, (1979).

With reference to Figure 4-7 and Table 4-12, Tables 4-22, 4-23, and 4-24 tabulate heat distribution subsystem component cost estimates as related to space and water heating applications of solar ponds in three locations, i.e., Boston, Massachusetts, Madison, Wisconsin, and Phoenix, Arizona.

Table 4-22. Energy Distribution Subsystem Cost Estimates

Application: 120,000-ft^2 Low-Rise Apartment, Space and Water Heating, Boston, Massachusetts (Atlantic Northeast Region)

Components	Description	Total Costs (U.S. $)			
<u>Hot Brine Loop</u>					
Pipe	2 1/2"ϕ, 720'	15,800	(7,900)[a]		
Heat Exchanger	1.100 x 10^6 Btu/h (550 ft^2)	5,500			
Pump	70 g/m	1,500			
Subtotal				22,800	(14,900)
<u>Transport Loop</u>					
Pipe	2 1/2"ϕ, 600'	13,200	(6,600)		
Pump	70 g/m	1,000			
Subtotal				14,200	(7,600)
<u>End-Use Components</u>					
Pipe	120 x (1/2"ϕ, 20')	38,400	(19,200)		
Heating Unit	120 x 360 cfm	36,000			
Water Heater	120 x 60 gal	36,000			
Pump and Fan	included above				
Subtotal				110,400	(91,200)
<u>Miscellaneous</u>					
Control and Instrumentation				13,300	(11,400)
<u>Total</u>				146,500	(125,100)

[a]Numbers in parenthesis are for low cost (plastic) pipe system.

Table 4-23. Energy Distribution Subsystem Cost Estimates

Application: 120,000-ft^2 Low-Rise Apartment, Space and Water Heating, Madison, Wisconsin (Great Lakes Region)

Components	Description	Total Costs (U.S. $)		
<u>Hot Brine Loop</u>				
Pipe	3"ϕ, 720'	18,000 (9,000)[a]		
Heat Exchanger	1.344 x 10^6 Btu/h (670 ft^2)	6,700		
Pump	90 g/m	2,000		
Subtotal			26,700	(17,700)
<u>Transport Loop</u>				
Pipe	3"ϕ, 600'	15,000 (7,500)		
Pump	90 g/m	1,500		
Subtotal			16,500	(9,000)
<u>End-Use Components</u>				
Pipe	120 x (1/2"ϕ, 20')	38,400 (19,200)		
Heating Unit	120 x 360 cfm	43,200		
Water Heater	120 x 60 gal	36,000		
Pump and Fan	included above			
Subtotal			117,000	(97,800)
<u>Miscellaneous</u>				
Control and Instrumentation			16,100	(12,500)
<u>Total</u>			176,900	(137,000)

[a]Numbers in parenthesis are for low cost (plastic) pipe system.

Table 4-24. Energy Distribution Subsystem Cost Estimates

Application: 120,000-ft^2 Low-Rise Apartment, Space and Water Heating, Phoenix, Arizona (Southwest Region)

Components	Description	Total Costs (U.S. $)			
Hot Brine Loop					
Pipe	1 1/2"ϕ, 720'	4,700	(2,400)[a]		
Heat Exchanger	0.515×10^6 Btu/h ($260\ ft^2$)	2,600			
Pump	35 gm	1,000			
Subtotal				8,300	(5,900)
Transport Loop					
Pipe	1 1/2"ϕ, 600'	10,500	(5,300)		
Pump	35 gm	700			
Subtotal				11,200	(5,900)
End-Use Components					
Pipe	120 x (1/2"ϕ, 20')	38,400	(19,200)		
Heating Unit	120 x 360 cfm	12,000			
Water Heater	120 x 60 gal	36,000			
Pump and Fan	included above				
Subtotal				86,400	(67,200)
Miscellaneous					
Control and Instrumentation				10,600	(7,900)
Total				116,500	(86,900)

[a]Numbers in parenthesis are for low-cost (plastic) pipe system.

SECTION 5

SURVEY OF POTENTIAL MARKET SECTORS

5.1 RESIDENTIAL, COMMERCIAL AND INSTITUTIONAL BUILDINGS SECTOR

5.1.1 Energy Demand for Space Heating/Cooling and Water Heating

The feasibility of using solar ponds for space heating was pointed out early by Rabl and Nielsen (1974). Solar ponds also are generally considered to be well-suited for domestic water heating. Solar ponds in most locations can easily meet temperature requirements for both uses, as experiments with field ponds have shown. Space cooling by solar ponds, however, remains to be demonstrated. The efficiency (or COP) of a cooling or refrigerating system by low-temperature thermal energy is generally very low, although further development effort may bring about improvement. Among the several ways solar ponds may be used for cooling and refrigeration purposes are the absorption, vapor-ejector driven and Rankine cycle-vapor compression processes.

The residential, commercial and institutional buildings sector consume a significant amount of energy, primarily in space heating, water heating, air conditioning, refrigeration and lighting. Major types of fuels consumed are electricity, gas and oil. According to data compiled by the Oak Ridge National Laboratory, 15.65 quads of energy was consumed in 1975 for residential buildings and 9.2 quads for commercial and institutional buildings (Tables 5-1 and 5-2). Table 5-3 breaks down the latter category by building type; retail and wholesale stores, schools and offices are the major energy consumers. The 24.85 quads used in 1975 should be compared with 15.9 quads for 1970 and 27.1 quads for 1979. The residential, commercial and institutional buildings sector in general consumes 35 to 37% of the total national energy expenditure. As can be seen in Tables 5-1 and 5-2, space heating, cooling and domestic water heating consume 67% of the energy used by the commercial and institutional buildings, and 73% of the energy used by the residential buildings.

Each state's 1979 energy consumption is listed by end-use sector and selected fuel type in Table 5-4. Here the commercial sector includes both commercial and institutional buildings. Except for the transportation sector, solar ponds can be expected to contribute a meaningful amount of energy to the remaining three sectors, residential, commercial and industrial. (The industrial sector is examined in Section 5.2.) Residential housing structures consist of several types: single family detached, single family attached, mobile homes and multi-family units. Table 5-5 shows occupied housing units in 1978-1979 by the various categories.

In projecting the future energy demand of the residential, commercial and institutional buildings sectors, it should be noted that the growth rate in energy demand has dramatically decreased in the 1970s. The reduction is due primarily to two factors: conservation and a decline in economic growth. Whereas population and income growth, and declining energy prices

Table 5-1. **Residential Energy Use By Fuel and End Use (1975) (Expressed in quads)**[a]

End Use	Electricity	Gas	Oil	Other[b]	Total
Space Heating	1.36	3.81	2.35	0.54	8.06
Water Heating	1.05	0.96	0.18	0.05	2.24
Refrigerators	0.92	0.00	0.00	0.00	0.92
Freezers	0.38	0.00	0.00	0.00	0.38
Cooking	0.46	0.29	0.00	0.01	0.76
Air Conditioning	1.08	0.00	0.00	0.00	1.08
Lighting	0.90	0.00	0.00	0.00	0.90
Other	0.86	0.45	0.00	0.00	1.31
Total	7.01[c]	5.51	2.53	0.60	15.65

[a]Source: Energy Division, Oak Ridge National Laboratory.
[b]Other fuels include coal, coke and LPG.
[c]Electricity values are in primary energy use: 11,500 Btu/kWh.

Table 5-2. Commercial and Institutional Energy Use By Fuel and End Use (1975) (Expressed in quads)[a]

End Use	Electricity	Gas	Oil	Other[b]	Total
Space Heating	0.33	1.66	1.88	0.12	3.99
Air Conditioning	1.83	0.14	0.00	0.00	1.97
Water Heating	0.04	0.08	0.10	0.00	0.22
Lighting	2.09	0.00	0.00	0.00	0.09
Other	0.76	0.17	0.00	0.00	0.93
Total	5.05[c]	2.05	1.98	0.12	9.20

[a]Source: Energy Division, Oak Ridge National Laboratory.
[b]Other fuels include coal, coke and LPG.
[c]Electricity values are in primary energy use: 11,500 Btu/kWh.

Table 5-3. Commercial and Institutional Energy Use By Building Type, 1975

Building type	Energy Use, 10^{15} Btu	Percentage of Total Energy Use
Retail-Wholesale	2.20	23.9
Educational	1.77	19.3
Finance and Other Office	1.44	15.7
Health	1.08	11.7
Hotel-Motel	0.56	6.1
Public Administration	0.40	4.3
Warehouse	0.32	3.5
Religious	0.20	2.8
Garages and Service Stations	0.09	1.0
Other	1.08	11.7
Total	9.20	100.0

increased energy consumption in the buildings sector from 10 to 26 quads between 1950 and 1973 (an annual growth rate of over 7%), the annual growth rate was reduced to 2% from 1973 to 1978 (Hartzler, 1980).

5.1.2 Building Energy Usage Patterns and Solar Pond Applicability

Space heating of buildings generally follows a "winter peaking" load pattern, while space cooling follows a "summer peaking" pattern. Domestic water heating, on the other hand, falls in the "baseload" category as hot water need is fairly constant throughout the year. Figure 5-1 presents some domestic hot water demand profiles that were studied by the Solar Energy Research Institute (SERI) (Farrington, et al, 1980). The "RAND use profile" is probably most typical of residential uses. These profiles assume that a typical household uses 80 gallons per day of hot water at a temperature of 120°F. Domestic hot water demand does not vary greatly with location; however, space heating and cooling loads are very sensitive to the climatic conditions of a region. Table 5-6 shows the heating and cooling loads calculated for a standard two-story ASHRAE single family dwelling with 1630 ft^2 of conditioned floor space, as located in the various cities of the country. It is evident that the heating load decreases while the cooling load increases as the dwelling location changes from the northeast to southwest. (The pattern for monthly variation of heating and cooling loads for all locations can also be discerned from Table 5-6). Table 5-7 and Figure 5-2 present the calculated energy requirements for a 30,000-ft^2 low-rise apartment complex located in Madison, Wisconsin; Table 5-8 and Figure 5-3 present the calculated energy requirement for a 50,000-ft^2 shopping center located in Boston, Massachusetts; Table 5-9 and Figure 5-4 present the load profile for a 50-family housing cluster located in Phoenix, Arizona. The "base-load" profile for domestic

Table 5-4. Consumption of Energy Summary, 1979: Trillion Btu[a]

State	Total Energy	Sources: Coal	Sources: Natural Gas	Sources: Petroleum	Sources: Nuclear	Sources: Hydro-electric	Sources: Other	Sources: Electricity Exchanges	End Use Sectors: Residential	End Use Sectors: Commercial	End Use Sectors: Industrial	End Use Sectors: Transportation
Alabama	[illegible]	662	289	661	216	121	0	228	217	147	1002	351
Alaska	[illegible]	5	161	129	0	5	0	10	39	32	137	81
Arizona	[illegible]	255	177	375	0	75	0	70	112	157	236	274
Arkansas	[illegible]	31	236	392	42	35	0	107	150	123	371	281
California	6112	68	1420	3621	91	351	81	330	1216	1167	1639	2361
Colorado	[illegible]	239	298	361	2	17	0	18	189	182	253	271
Connecticut	[illegible]	1	69	583	137	5	0	15	211	142	212	191
Delaware	219	24	26	165	0	0	0	-6	40	37	90	52
Dist. of Col.	[illegible]	3	30	60	0	0	0	62	41	43	42	29
Florida	[illegible]	201	353	1710	166	3	0	11	511	429	561	926
Georgia	[illegible]	470	318	805	55	46	0	5	326	239	557	567
Hawaii	[illegible]	0	0	265	0	1	0	7	23	21	69	[illegible]
Idaho	[illegible]	16	55	145	0	96	0	68	76	68	135	93
Illinois	[illegible]	852	1161	1708	296	1	0	1	926	746	1430	[illegible]
Indiana	[illegible]	1170	513	896	0	5	0	21	458	279	1396	471
Iowa	[illegible]	227	297	499	31	9	0	50	258	173	426	259
Kansas	[illegible]	148	597	441	0	*	0	-33	194	167	494	290
Kentucky	[illegible]	611	223	613	0	41	0	25	257	177	635	342
Louisiana	[illegible]	3	2020	1211	0	0	0	76	283	372	2083	580
Maine	[illegible]	1	2	261	48	63	0	-23	85	35	140	94
Maryland	[illegible]	235	175	633	101	23	0	33	257	200	428	318
Massachusetts	[illegible]	4	159	1011	65	5	0	*	372	287	242	384
Michigan	[illegible]	759	892	1067	161	14	*	9	720	430	1052	693
Minnesota	[illegible]	241	340	613	124	29	*	28	308	179	529	350
Mississippi	[illegible]	60	260	608	0	0	0	68	156	154	421	259
Missouri	[illegible]	518	354	679	0	11	0	-38	495	303	373	447
Montana	[illegible]	65	71	185	0	109	1	-40	61	54	178	91
Nebraska	[illegible]	81	173	238	93	13	0	-36	127	102	198	155
Nevada	[illegible]	99	87	110	0	18	0	45	61	52	75	112
N. Hampshire	[illegible]	29	9	141	0	13	0	*	61	22	45	66
N. Jersey	[illegible]	59	256	1401	71	3	0	275	442	395	681	551
N. Mexico	466	153	216	215	0	1	0	-119	66	77	151	172
N. York	[illegible]	313	636	2575	199	401	1	24	955	906	1149	1072
N. Carolina	[illegible]	560	133	815	73	63	0	45	383	725	621	479
N. Dakota	251	150	30	149	0	63	0	-137	56	40	91	72
Ohio	4212	1662	914	1437	34	*	*	197	835	521	2072	814
Oklahoma	[illegible]	62	845	454	0	24	0	-86	221	191	570	317
Oregon	[illegible]	6	95	391	48	312	2	75	199	169	290	270
Pennsylvania	[illegible]	1720	754	1686	202	13	0	-183	881	475	1929	847
Rhode Island	[illegible]	*	28	121	0	*	0	50	64	44	38	54
S. Carolina	[illegible]	708	122	432	196	41	0	-21	176	136	404	262
S. Dakota	221	36	25	137	0	66	0	-42	54	33	68	69
Tennessee	[illegible]	545	231	582	0	128	0	258	357	215	691	448
Texas	[illegible]	616	4096	3661	0	12	1	-23	1009	840	4642	1881
Utah	[illegible]	171	128	205	0	8	0	8	108	68	218	129
Vermont	121	*	4	75	37	11	*	-5	43	17	27	37
Virginia	1531	215	137	921	76	16	0	167	367	268	396	503
Washington	[illegible]	101	161	601	39	830	0	-154	346	218	573	438
W. Virginia	[illegible]	825	151	237	0	13	0	-420	138	79	435	152
Wisconsin	1461	328	374	611	112	24	*	9	371	242	495	353
Wyoming	423	281	95	199	0	11	0	-165	37	35	264	87
United States	[illegible]	15109	20661	37122	2748	3166	89		15411	11741	31383	20426

* Represents small, non zero value.

Note: Totals may not equal sum of components due to independent rounding.

Note: U.S. Total Energy and U.S. Industrial numbers include 66 trillion Btu of net imports of coal coke which was not allocated to the states. End use sector data include electricity sales and associated electrical energy losses.

[a]Source: U.S. Department of Energy, 1981.

Table 5-4. Consumption of Energy Summary, 1979: Trillion Btu[a]

State	Total Energy	Sources: Coal	Natural Gas	Petroleum	Nuclear	Hydro-electric	Other	Electricity Exchanges	End Use Sectors: Residential	Commercial	Industrial	Transportation
Alabama	1741	662	299	661	216	121	0	225	217	117	1002	353
Alaska	261	5	161	129	0	5	0	19	30	37	115	81
Arizona	549	25	177	375	0	75	0	70	112	157	206	274
Arkansas	667	31	276	192	42	35	0	105	170	121	371	291
California	6112	65	1470	3621	91	351	81	310	1206	1067	1659	2651
Colorado	695	211	290	301	2	17	0	19	167	192	251	271
Connecticut	752	1	61	561	137	5	0	15	211	142	212	191
Delaware	215	24	26	165	0	0	0	-6	40	37	89	62
Dist of Col	175	3	30	60	0	0	0	62	41	41	42	27
Florida	2161	201	351	1710	166	3	0	11	511	429	561	926
Georgia	1655	470	318	805	55	46	0	5	326	279	557	567
Hawaii	261	0	0	255	0	1	0	7	21	21	69	154
Idaho	319	16	55	145	0	96	0	68	76	65	135	93
Illinois	4029	852	1161	1709	296	1	0	1	926	706	1439	956
Indiana	2661	1170	513	896	0	5	0	21	458	279	1396	471
Iowa	1118	227	297	499	31	9	0	50	258	173	426	259
Kansas	1115	148	597	481	0	*	0	-33	194	167	494	260
Kentucky	1012	611	221	617	0	41	0	25	257	177	635	342
Louisiana	3317	3	2020	1211	0	0	0	76	293	212	2093	509
Maine	355	1	2	261	48	67	0	-21	85	25	140	94
Maryland	1203	235	175	671	101	27	0	33	257	209	428	318
Massachusetts	1256	4	159	1011	65	5	0	*	372	297	242	394
Michigan	2956	759	892	1057	161	14	*	9	720	430	1072	693
Minnesota	1135	241	300	613	121	29	*	29	306	179	529	308
Mississippi	901	60	260	606	0	0	0	69	176	154	471	279
Missouri	1535	518	351	679	0	11	0	-39	495	303	373	447
Montana	337	65	71	105	0	109	1	-40	61	51	178	91
Nebraska	512	81	173	216	93	13	0	-36	127	102	190	155
Nevada	256	99	87	109	0	18	0	45	61	62	75	112
N Hampshire	191	29	9	141	0	13	0	*	61	22	45	66
N Jersey	2012	39	256	1401	71	3	0	275	482	395	691	551
N Mexico	466	153	216	215	0	1	0	-119	66	77	151	172
N York	4051	317	636	2575	199	401	1	21	955	906	1109	1072
N Carolina	1709	560	133	815	73	63	0	45	393	225	621	479
N Dakota	265	159	30	149	0	63	0	-137	56	40	98	72
Ohio	4212	1652	914	1437	34	*	*	197	835	621	2072	814
Oklahoma	1299	62	845	454	0	24	0	-86	221	191	570	317
Oregon	925	6	95	391	49	312	2	75	199	169	290	279
Pennsylvania	4255	1779	751	1696	202	13	0	-103	891	475	1929	947
Rhode Island	190	*	29	121	0	*	0	50	64	44	38	54
S Carolina	915	204	122	432	196	41	0	-21	176	136	404	262
S Dakota	221	36	25	137	0	66	0	-42	54	33	69	69
Tennessee	1741	565	231	562	0	129	0	259	357	215	694	440
Texas	9372	616	4696	3661	0	12	1	-23	1009	840	6542	1981
Utah	527	171	128	205	0	8	0	8	108	68	210	129
Vermont	124	*	4	75	87	81	*	-5	63	17	27	37
Virginia	1531	215	137	921	76	16	0	167	367	269	395	503
Washington	1516	101	161	691	39	930	0	-154	346	218	573	438
W Virginia	891	825	151	237	0	13	0	-470	138	79	435	182
Wisconsin	1461	325	374	611	112	26	*	9	371	242	495	353
Wyoming	423	251	95	199	0	11	0	-165	27	36	264	97
United States	78961	15109	20661	37122	2749	3166	89		15411	11741	31389	20426

* Represents small, non-zero value.
Note: Totals may not equal sum of components due to independent rounding.
Note: U.S. Total Energy and U.S. Industrial numbers include 66 trillion Btu of net imports of coal coke which was not allocated to the states. End use sector data include electricity sales and associated electrical energy losses.

[a]Source: U.S. Department of Energy, 1981.

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Table 5-5. Occupied Housing Units by Region and Type of Housing Structure: 1978 to 1979[a]

Type	Number (1,000)					Percent Distribution				
	Total	North-east	North-Central	South	West	Total	North-east	North-Central	South	West
Total units	76,604	17,363	20,614	24,603	14,028	100.0	100.0	100.0	100.0	100.0
Single family detached	48,547	7,915	15,493	16,940	8,199	63.4	45.6	75.2	68.9	58.4
Single family attached	3,128	1,614	578	497	439	4.1	9.3	2.8	2.0	3.1
2-4 unit buildings	10,743	4,240	2,795	2,006	1,709	14.0-	24.4	13.6	8.2	12.2
5 or more unit buildings	9,151	3,112	793	2,284	2,961	11.9	17.9	3.8	9.3	21.1
Mobile home	4,505	352	890	2,843	720	6.3	2.0	4.3	11.6	5.1
Other	228	130	65	33	[c]	.3	.7	.3	.1	[c]

[a]Source: U.S. Energy Information Administration, 1980.

[b]As of winter 1976-1979 excludes Alaska and Hawaii; covers year-round units only for composition of regions.

[c]Represents zero or rounds to zero.

Table 5-5. Occupied Housing Units by Region and Type of Housing Structure: 1978 to 1979[a]

Type	Number (1,000)					Percent Distribution				
	Total	North-east	North-Central	South	West	Total	North-east	North-Central	South	West
Total units	76,604	17,363	20,614	24,603	14,028	100.0	100.0	100.0	100.0	100.0
Single family detached	48,547	7,915	15,493	16,940	8,199	63.4	45.6	75.2	68.9	58.4
Single family attached	3,128	1,614	578	497	439	4.1	9.3	2.8	2.0	3.1
2-4 unit buildings	10,743	4,240	2,795	2,006	1,709	14.0-	24.4	13.6	8.2	12.2
5 or more unit buildings	9,151	3,112	793	2,284	2,961	11.9	17.9	3.8	9.3	21.1
Mobile home	4,505	352	890	2,843	720	6.3	2.0	4.3	11.6	5.1
Other	228	130	65	33	[c]	.3	.7	.3	.1	[c]

[a]Source: U.S. Energy Information Administration, 1980.

[b]As of winter 1976-1979 excludes Alaska and Hawaii; covers year-round units only for composition of regions.

[c]Represents zero or rounds to zero.

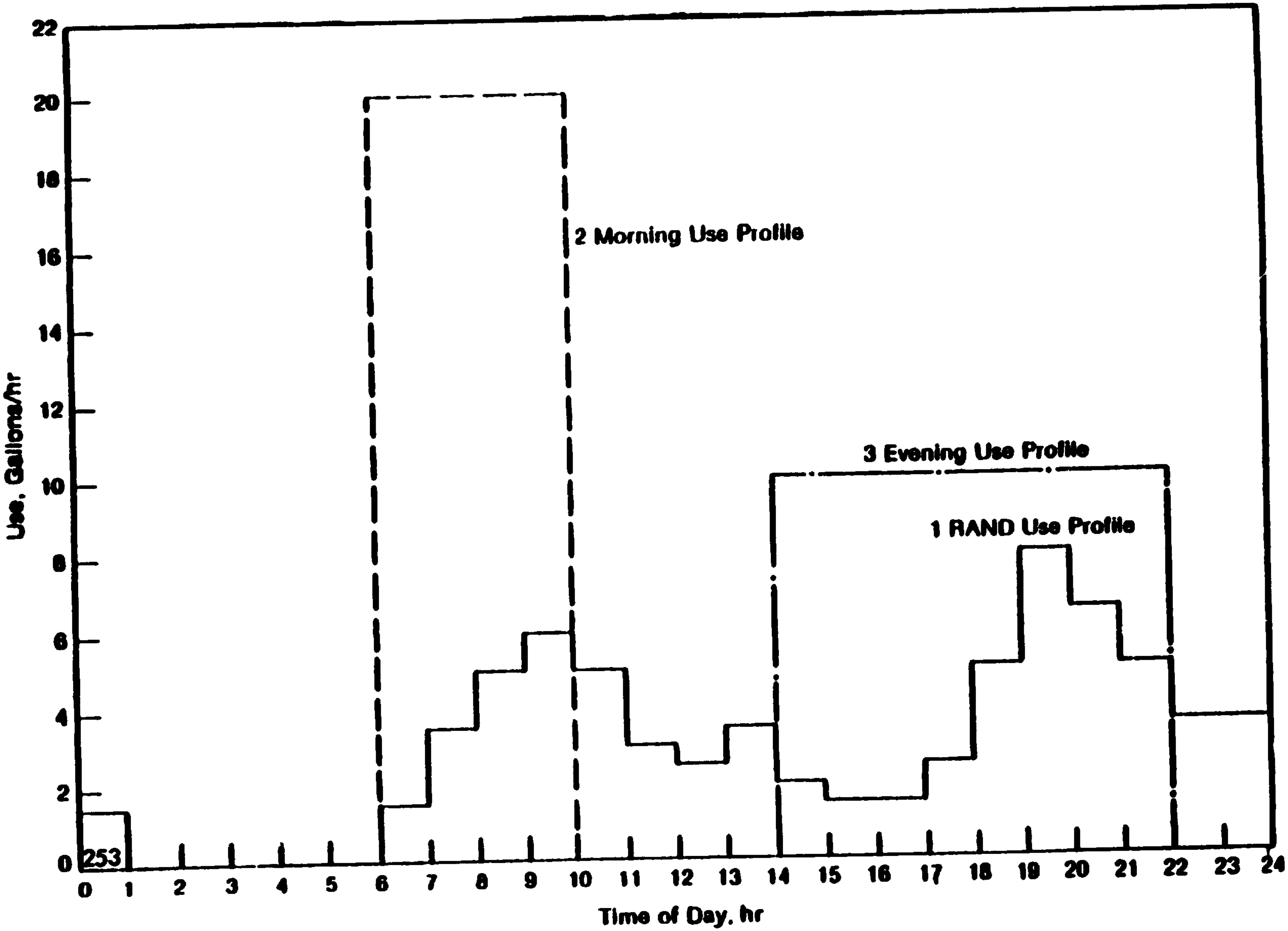


Figure 5-1. Domestic Hot Water Demand Profiles, Described in Terms of Use vs Time of Day (Source: Farrington, et al, 1980)

Table 5-6. Example of Monthly Heating and Cooling Loads (10^6 Btu)

	Boston		New York		Fort Worth		Santa Maria		Phoenix	
	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling
Jan.	15.78	0	13.74	0	6.2	0	2.47	0	2.67	0
Feb.	10.83	0	10.95	0	2.24	0.22	2.22	0	1.52	0
March	8.455	0	7.4	0	1.76	0.356	0.25	0	0.17	1.75
April	3.55	0	0	0.34	0	2.6	0.09	0	0	4.09
May	1.72	1.78	2.07	1.38	0	9.79	0.18	0.44	0	5.85
June	0	6.57	0	10.36	0	16.78	0	0	0	16.55
July	0	8.82	0	12.1	0	20.44	0	2.42	0	17.47
Aug.	0	8.73	0	12.44	0	19.32	0	2.48	0	16.53
Sept.	0.215	2.48	0	5.42	0	10.01	0	2.11	0	13.04
Oct.	1.65	0	0.34	0.14	0	5.80	0	1.15	0	5.20
Nov.	6.91	0	4.66	0	1.37	1.35	0.23	0.22	0	1.51
Dec.	13.71	0	14.74	0	5.10	0	1.40	0	1.95	0
Annual Total	62.51	28.73	51.14	36.56	17.66	86.68	6.32	9.29	6.32	82.21

Table 5-7. Summary of Energy Requirements for a Low-Rise Apartment, 30,000 ft^2 (20 t 30 Units) Madison, Wisconsin

	Heating, 10^6 Btu	Hot Water, 10^6 Btu	Cooling, 10^6 Btu
January	153.3	37.4	0
February	124.8	37.4	0
March	113.7	37.4	0
April	100.2	37.4	0
May	45.3	34.6	0
June	5.4	32.0	25.2
July	0	32.0	35.1
August	0	32.0	36.9
September	21.0	34.6	2.7
October	46.2	37.4	0
November	103.2	37.4	0
December	165.0	37.4	0
Total	877.8	427.0	99.9

water heating, the "winter peaking" profile for space heating, and the "summer peaking" profile for space cooling are evident from these figures and tables. The relative weights of heating, cooling and hot water loads bear out the weather patterns in these locations as expected.

The load profile significantly affects the design of a solar pond. Space heating in colder regions normally will require a deep pond, whose large storage capacity enables collecting solar heat during the summer months for winter use. A pond designed primarily for space cooling in warmer regions can be relatively shallow, as long-term storage of thermal energy will not be required.

Hot water for household use normally requires a temperature from 120 to 140°F. Hot water for washing and other sanitary purposes such as in hospitals and cafeterias requires a temperature of 180°F. Conventionally, hot air circulation for space heating requires a temperature from 90 to 120°F, depending on the heating system and circulation distance. In the design of solar pond systems, a 10 to 20°F temperature drop provision must be made for losses which occur across a heat exchanger and along the transport lines. This means that hot brine withdrawn from the pond must be at least 110 to 140°F to be useful for space heating, and at higher temperatures for domestic water heating.

As for cooling, Aqua-ammonia and LiBr-H_2O systems are presently available for commercial absorption air conditioning. Both prefer a generator temperature of higher than 180°F. However, the LiBr-H_2O system may work at a generator temperature as low as 140°F if condenser temperature lower than 80°F is available.

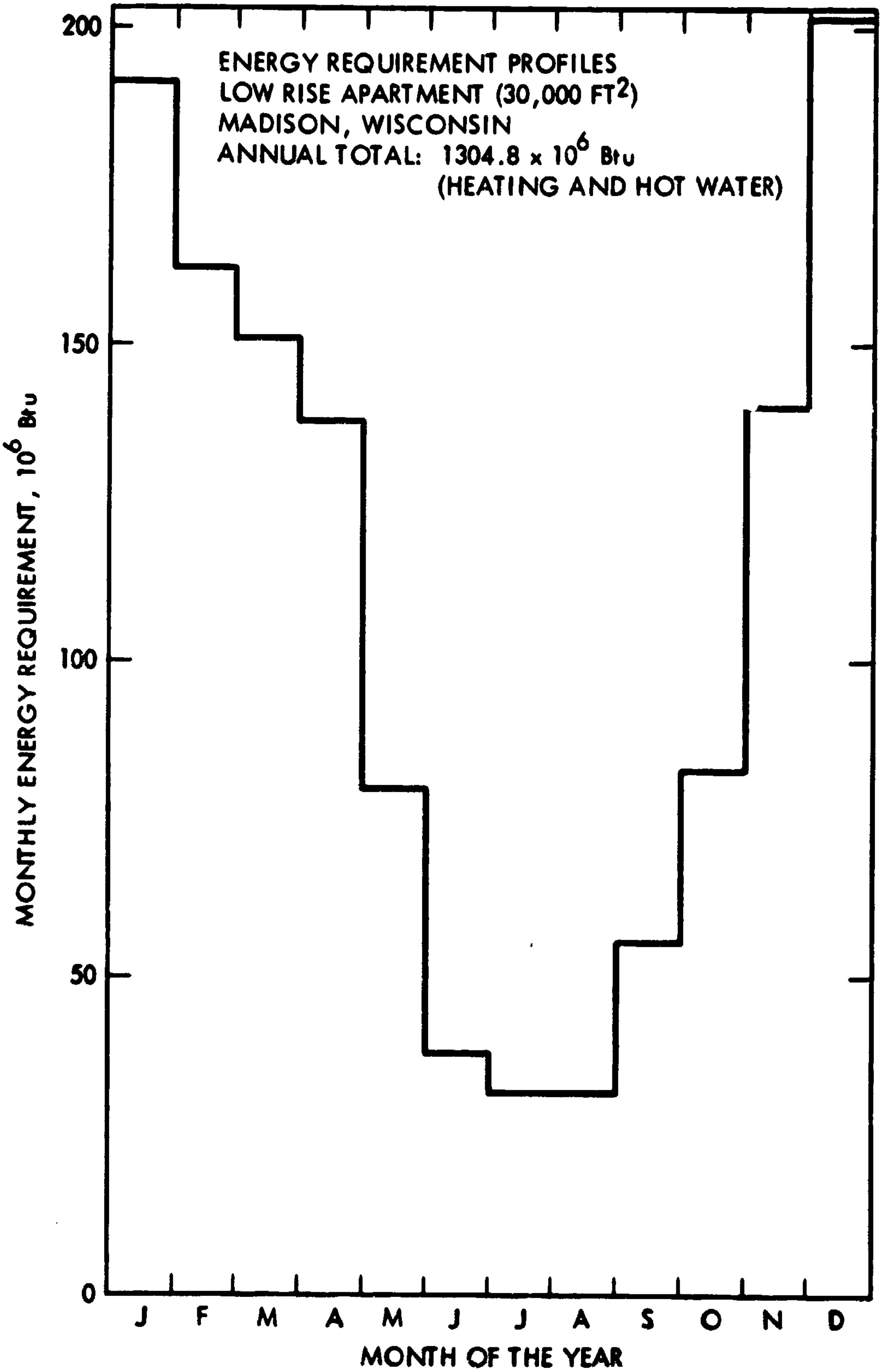


Figure 5-2. Energy Requirements for a 30,000-ft^2 Low-Rise Apartment Complex in Madison, Wisconsin

Table 5-8. Summary of Energy Requirements for a Shopping Center (50,000 ft^2) Boston, Massachusetts

	Heating, 10^6 Btu	Hot Water, 10^6 Btu	Heating and Hot Water, 10^6 Btu
January	876.88	8.92	885.80
February	765.491	8.92	774.41
March	658.85	8.92	667.77
April	388.67	8.92	397.59
May	172.22	8.92	181.14
June	21.33	8.92	30.25
July	0	8.92	8.92
August	6.32	8.92	15.24
September	60.04	8.92	68.96
October	237.79	8.92	426.71
November	469.25	8.92	478.17
December	783.66	8.92	792.53
Total	4440.50	107.00	4547.50

5.1.3 Land Availability and Other Considerations

Most solar ponds will not be insulated along the sides and at the bottom. Heat losses through the pond sides to the surrounding earth are substantial, especially for smaller ponds. Consequently, a very small pond to serve the energy needs of a single family dwelling is not practical. A larger pond (at least 1/3 acre) serving a group of dwellings is preferred; i.e., district heating. Also, retrofitting existing buildings with solar ponds is likely to encounter many constraints, such as land availability and landscape problems. (See Appendix I for examples of land-use patterns.) Therefore, application of solar ponds in developed areas will be much more limited than in undeveloped areas. In undeveloped areas, appropriate considerations can be easily given to solar ponds during the planning phase of a project, and solar ponds can be integrated into the landscape design. For these reasons, the Benham Group land survey has emphasized undeveloped areas of a city and land-availability data in the multi-family-dwelling sector. The Benham Group analysis assumes that 34% of the undeveloped land in the commercial and institutional buildings sector can be regarded as pond-suitable land, while the percentage for the residential dwellings sector varies with region because of differences in local zoning regulations. The single-family/multi-family breakdown was calculated according to the national average of 87 and 13% for single- and multi-family, respectively. These data are included in Tables 2-1 through 2-9, and more detailed information on the 30 case study cities can be found in the Benham Group report (1982).

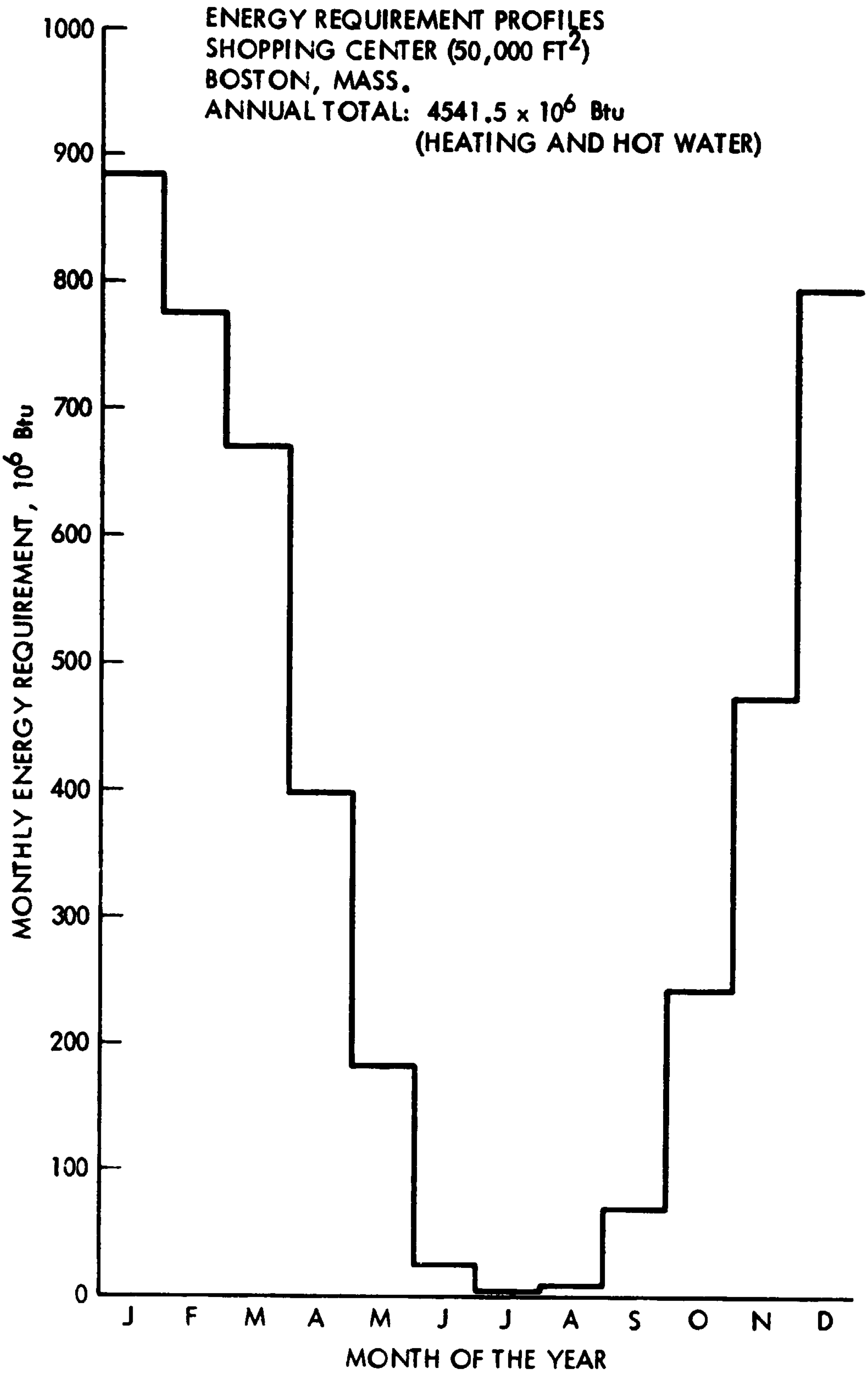


Figure 5-3. Energy Requirement for a 50,000-ft^2 Shopping Center

Table 5-9. Summary of Energy Requirements for a 50-Family Housing Cluster, Including Cooling Requirements, in Phoenix, Arizona

	Heating, 10^6 Btu	Hot Water, 10^6 Btu	Cooling(Absorption Air Conditioner with COP = 0.5) 10^6 Btu
January	133.5	93.5	0
February	76.0	93.5	0
March	8.5	93.5	175.0
April	0	93.5	405.0
May	0	86.5	585.0
June	0	80.0	1655.0
July	0	80.0	1747.0
August	0	80.0	1653.0
September	0	86.5	1304.0
October	0	93.5	520.0
November	0	93.5	151.0
December	97.5	93.5	0
Total	316.0	1067.5	8221.0

As noted in Section 2.1.2, the deployment of solar ponds in the buildings sector will be limited more by land availability than salts or water resources. Solar ponds for building heating/cooling and domestic water heating can be much smaller than electricity-generating ponds, and salt purchase is considered an economic possibility. The land-availability information derived from the Benham Group study is useful for a regional assessment, but a site-specific survey will be required in developing any specific project.

5.1.4 Potential for Solar Ponds in the RCI Buildings Sector

The regional energy consumption in the residential, commercial and institutional (RCI) buildings sector was computed from the 1979 data base as given in Table 5-4 and tabulated in column (1) of Table 5-10. According to Tables 5-1 and 5-2, the energy consumed in space heating/cooling and water heating is 73 and 67% of the total RCI consumption for the residential and commercial (including institutional) buildings, respectively. An average of 70% is thus applied to the column (1) figures to derive the regional energy consumption for building space heating/cooling and domestic water heating, shown in column (2) of Table 5-10. Using an annual growth rate of 2% as discussed in Section 5.1.1, consumption for the year 2000 is projected and listed in column (3) of Table 5-10.

Clearly, pond potential in the RCI buildings sector will not be limited by energy need, but by the availability of resources, especially

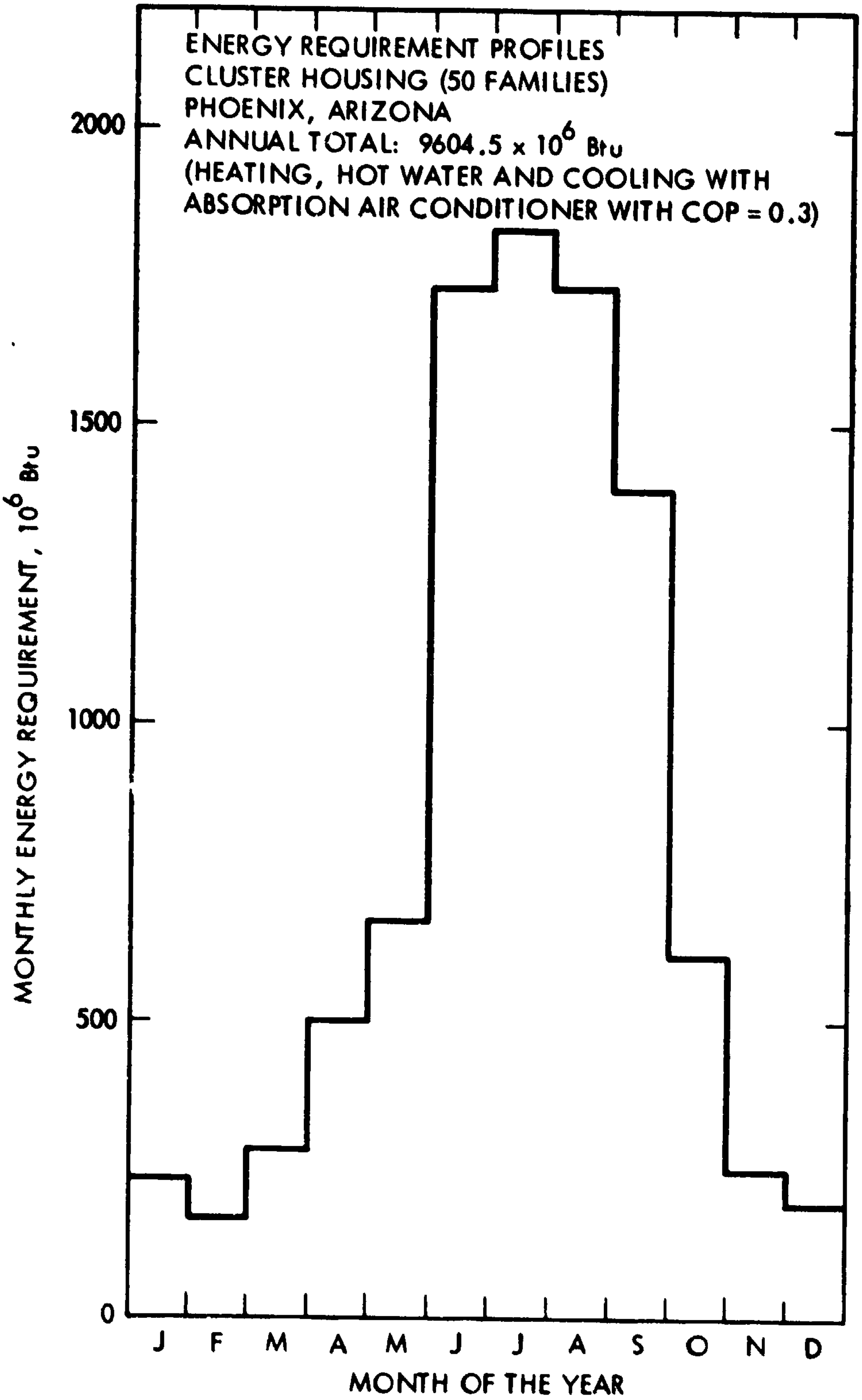


Figure 5-4. Energy Requirements for a 50-Family Housing Cluster in Phoenix, Arizona

Table 5-10. Year 2000 Projection of Energy Consumption and Estimation of Pond Potential in the Residential, Commercial and Institutional Buildings Sector

Region	(1) 1979 RCI Consumption, quads	(2) 1979 Space & Water Heating/Cooling, quads	(3) 2000 Projection Space & Water Heating/Cooling, quads	(4) Estimated Land Availability, acre	(5) Average Pond Thermal Output at 60°C, 10^9 Btu/acre/yr	(6) Estimated Pond Potential in RCI Sector, quads
Pacific Northwest	1.08	0.76	1.13	58,797	3.86	0.23
Salt Lake	1.44	1.01	1.50	10,279	5.59	0.06
Southwest	2.07	1.45	2.16	37,403	7.64	0.29
Black Hills	0.60	0.42	0.63	8,961	3.06	0.03
Red River	2.62	1.83	2.73	197,131	5.48	1.08
Great Lakes	6.45	4.52	6.73	76,303	2.70	0.21
Tennessee Valley	4.11	2.88	4.29	135,133	4.67	0.63
Gulf Coast	3.21	2.25	3.35	57,433	5.07	0.29
Atlantic Northeast	5.46	3.82	5.69	183,992	2.42	0.45
Alaska	0.06	0.04	0.06	b	0.00	b
Hawaii	0.04	0.03	0.04	b	7.00	b
Puerto Rico	a	a	a	b	7.10	b
U.S.A.	27.14	19.00	28.31	765,432		3.27

[a]Information not available.

[b]Not estimated.

low-cost land. Consequently, the Benham Group land-survey results (presented in Section 2.1.2) are used for estimation. The following assumptions are made in using the Benham Group "pond-suitable land" (PSL) data (Tables 2-10 and 2-11): 68% of the undeveloped multi-family PSL, 32% of the undeveloped single-family PSL, and 36% of the undeveloped commercial and institutional PSL will be considered as actually available for pond construction. Several remarks must be made here: (1) Only undeveloped land is considered, and retrofitting ponds in developed areas is excluded from this estimate; (2) the Benham Group has taken fractions of the undeveloped acres in their estimation of undeveloped PSL, e.g., 34% for the commercial and institutional categories, and 15 to 46% for the residential category depending on the region; (3) the further reductions of 68%, 32% and 36% made here reflect an added conservatism to account for other possible land usage and the unsuitability of certain housing development patterns to incorporate solar ponds. The varying weights reflect the expectation that more ponds will be built for multi-family complexes than for commercial, institutional and single-family residential buildings.

Applying the above assumption on the Benham Group data (Tables 2-10 and 2-11), estimates on available land for pond construction are computed for each region and listed in column (4) of Table 5-10. These are multiplied by the average regional pond thermal outputs, which were calculated through the performance analyses in Section 3.2 and which are tabulated in column (5) of Table 5-10, to obtain the pond potential estimates for the RCI buildings sector, presented in column (6). As shown in the table, the Red River region possesses the highest potential, 1.08 quads/yr, followed by the Tennessee Valley and Atlantic Northeast regions. The total potential in the RCI buildings sector for the year 2000 is estimated to be 3.27 quads/yr. "Pond potential" will be defined and discussed in Section 7.2.

5.2 INDUSTRIAL PROCESS HEAT SECTOR

5.2.1 Survey Methodology

There are different definitions of the term "industry." In many of the U.S. sector projections of energy consumption, industry includes agriculture, mining, and manufacturing. In other documents, industry is just the manufacturing sector. For this report, the term industry includes just the manufacturing sector, Standard Industrial Classification (SIC) Code Categories 20-39. Mining is not included in any of the quantitative evaluations of industrial potential for solar ponds, but it is included in some qualitative discussions in this report.

This section will focus on the potential demand for solar ponds to provide low-temperature industrial process heat. Existing information was used whenever possible, with selected telephone interviews to provide supplemental data when needed. Solar pond use for other than thermal process heat applications was only qualitatively examined. It is not included in the estimate of potential demand.

To examine the rather large industrial data base for processes where solar ponds might provide thermal energy, the following criteria were emphasized:

(1) Industries with thermal energy requirements less than 200°F.

(2) Industries with sufficient need for low-temperature thermal energy that even if all cost-effective conservation were done, primary energy would still be required to provide the low-temperature thermal energy. There was insufficient data to disaggregate energy use in this manner. Only some food processing, furniture, and leather products industries appear to meet this requirement.

(3) Industries located outside of Standard Metropolitan Statistical Areas (SMSA). It is assumed that land area would more likely be available outside SMSAs.

(4) Industries that already use ponds within the industrial operation for such purposes as waste holding, aeration, settling, tailing, and disposal. Where existing ponds were present, the conversion or integration with a solar pond could be an economic incentive for early solar pond use. Therefore, the location and number of current pond sites were examined and any other characteristics which appeared pertinent.

(5) Industries located in areas with higher levels of insolation.

(6) Manufacturing processes that produce salts or brine as by-products.

In order to assess the feasibility of using solar ponds in industrial applications, the following steps were taken.

5.2.1.1 Assessing and Acquiring the Appropriate Data. A considerable amount of research and investigation on industrial energy consumption has been undertaken since the inception of the U.S. Department of Energy. Three primary types of data sources were used in this study:

(1) Previous industrial energy surveys and specific solar IPH studies including the Intertechnology (1977) Report, SERI Market Characterization (Ketels and Reves, 1979), and Insights West Surveys (Insight West, 1980; Wilson, et al, 1980).

(2) The 1976 Annual Survey of Manufacturers, Industrial Fuels and Electric Energy Consumed (U.S. Bureau of Census, 1979).

(3) The Environmental Protection Agency (EPA) Impoundment (pond) data.[1]

In addition, telephone interviews with selected industries and other researchers in the field were conducted.

The three primary data sources are not entirely consistent with each other. Data were collected for different purposes, spanned different years, and applied different standards. The Annual Survey of Manufacturers was completed for all manufacturing firms having at least 10 full-time employees; thus, virtually all manufacturing firms were included in this data. The EPA impoundment study was completed on all known industrial ponds, including manufacturing, agriculture, mining, and municipal ponds. However, the EPA findings have not yet been released in their entirety. Consequently, only the most cursory aggregate data on the number and state location of the ponds at national and state level was available.

Finally, the government-sponsored research studies on industry have used Census of Manufacturer's data as input to their analyses. However, the particular year's input figures have varied depending on when the studies were done and which census year was used. As mentioned previously, this report covers only SIC Codes 20-39. It does not consider the agricultural, mining or construction industries, SIC Codes 01-19. Although no specific documentation of low-temperature energy use was found for the mining industry, studies at JPL show that there could be potentially new innovative uses for ponds (Carpenter, et al, 1981). The uses are highly site- and process-specific. Therefore, no attempt was made to quantify the potential as insufficient data were available to estimate the energy requirements for such applications.

5.2.1.2 Screening Thermal Energy Requirements in Industry by Three-Digit SIC Code Category. To determine the process temperatures and the ratio of low/high or low/total energy consumed by industry, the 1977 ITC report and the 1980 SERI Market Characterization (Ketels, 1979) reports were used. From the total list of industries in SIC Code 20-39, those industries with thermal processes under 200°F were abstracted. Although the list is not exhaustive, it covers the majority of known low-temperature process heat uses in those manufacturing industries.

Once the processes were listed, the 1976 U.S. Census of Manufacturers (U.S. Bureau of Census, 1979) was used to determine, by 3-digit SIC code, those industries with low-temperature process heat requirements; the total and thermal energy consumed by state; the amount of total and thermal energy consumed by Standard Metropolitan Statistical Area (SMSA); and, by subtracting the thermal energy consumed within the SMSAs from the total thermal energy consumed by state, the total non-SMSA energy consumption in the industrial sector.

[1]Data Supplied by Mr. Charles Kleeman, Groundwater Protection Section, Environmental Protection Agency, Region III, Philadelphia, Pennsylvania.

The 1977 ITC report was used to determine at the 3-digit SIC Code level, the ratio of low-temperature thermal energy to total thermal energy for those industries with less than 200°F thermal energy requirements. The ratio of 200°F energy to total thermal energy was then used to calculate for each state the number of Btu used in that temperature range for each 3-digit SIC Code category.

5.2.1.3 Assessing Characteristics of Industry. Each industrial sector is characterized by its unique productive processes and energy demand profiles. These were examined as far as information was available. Particular attention was paid to existing ponds and land area availability. To determine the potential impact of existing ponds, an EPA survey on waste disposal ponds or impoundments was used (see Footnote 1). Undertaken in 1977-78, this survey was done for all sectors of the economy including the industrial, municipal, mining and agricultural sectors. It is the only known national assessment of existing ponds that has been undertaken, completed, and documented by all 50 states. However, the EPA findings are still under review. Therefore, only rough data were obtained. California and Nevada were the only states with data available in any detail (State of Nevada, 1979; Casamajor, 1980).

Land area availability is particular to a specific firm and the data are neither aggregated in any SIC code fashion, nor reflected in the Census energy consumption figures. Therefore, a measure had to be found that could be used to draw some rough assumptions about energy and land area availability. The SMSA, non-SMSA bifurcation was used as that rough measure.

SMSAs are urban nodes and are generally built up. Land costs are high and land is highly utilized. The SMSA classification is based on density assumptions of urban development. Density is the number of people or buildings per unit of land area. It was assumed that sufficient land area for solar ponds was less likely to be available within SMSAs, and that land was more likely to be available in non-SMSA areas. Whether the soil conditions or terrain were suitable for solar ponds was not examined.

SMSA energy consumption is only documented by a 2-digit SIC Code. Therefore, to determine how much SMSA thermal consumption is low temperature, the following ratio was used:

$$\frac{\left[\begin{array}{c}\text{State total low-temperature energy}\\ \text{use by 3-digit SIC code Category}\end{array}\right]}{\left[\begin{array}{c}\text{State total thermal energy consumed at the}\\ \text{2-digit level of the same SIC Code category}\end{array}\right]}$$

That ratio or percentage was multiplied by the 2-digit SMSA thermal consumption figure to arrive at the amount of low-temperature thermal energy consumed within the SMSA. This last figure was then subtracted from the total state low-temperature thermal energy consumption to arrive at the non-SMSA energy consumed at less than 200°F. The ratio of 3-digit to 2-digit energy consumption in each 2-digit category was assumed to be the same for the SMSA and non-SMSA cases. For those SMSAs which crossed state boundaries, the SMSA was assigned to a particular state and the calculations performed in the same manner.

There are many factors not taken into consideration such as those urban industries that have significant amounts of land. For example, in the chemical industry land may be used as a buffer between a plant and the surrounding community. Also, open space is a feature in many of the newer industrial park developments and might be available for solar pond sites. Likewise, non-urban land might be highly productive agricultural land or mountainous terrain and not available. However, limited by the scope of the study, these factors were not quantified, but were recommended for future site-specific study.

5.2.1.4 Evaluating Solar Pond Potential. Regional solar pond potential was finally evaluated based on energy consumption and other characteristics of each industrial sector, and regions of high solar pond applicability were indicated.

5.2.2 Thermal Energy Use in Industry

Industry consumed 12.6 x 10^{15} Btu of energy (thermal and electric) in 1976, of which 10.5 x 10^{15} Btu was for purchased fuels (U.S. Bureau of Census, 1979). Purchased fuels included industrial process heat, feedstock and fuel used to generate on-site electricity.

There are 19 categories, SIC Code classifications 20-39, in the industrial sector, within which energy use varies considerably. As shown in Table 5-11, the top six SIC Code industries consume 80% of all industrial energy.

Just as energy is concentrated in a few industries, the location of the top energy-consuming industries is also concentrated. Over 60% of all U.S. industrial manufacturing is found in three geographic regions as represented by the shaded areas in Figure 5-5. California consumes 10% of total industrial energy use; Texas, Louisiana and Alabama, 32%; and the Northcentral and Northeast consume 22%. The remaining 38% is dispersed throughout the U.S. The concentrations depend on patterns of urban development, proximity to markets, transportation, and the availability of raw materials, labor and energy resources. All these factors will impact the cost of energy to an industry and to the ultimate potential for solar ponds.

Note that around 40% of the industrial energy is consumed in areas that have greater than 500 Btu/ft^2/day of useful energy. These areas will most likely be the early areas of solar pond interest and construction.

Extensive surveys of industrial energy use have been conducted (Energy and Environmental Analysis Inc., 1978; Ultrasystems Inc.; U.S. Department of Energy, 1978) as well as specific market studies of the potential for particular solar technologies (Battelle Columbus Laboratories, 1977; Intertechnology Corp., 1977; Insights West, 1980; Wilson, et al, 1980; Barbieri, 1978). Although electrical energy consumed differs between plants only in the type of current (ac or dc) and amount used, thermal energy varies in temperature, form (hot air, hot water, steam) and quantity. The temperatures required by industrial process are generally defined as low, medium and high. Low temperatures are under 212°F; medium are 212 to 550°F; high temperatures are over 550°F. Steam is the most common medium of heat

Table 5-11. Process Heat Requirements in Major Industrial Groups, 1976

SIC Code	Industrial Group	Thermal Energy Use (10^{15} Btu/yr) 1 2 3 4
33	Primary Metals	----------------------
29	Petroleum and Coal Products	-----------------
28	Chemicals and Allied Products	------------
26	Paper and Allied Products	-----------
32	Stone, Clay and Glass Products	----------
20	Food and Kindred Products	---------
22	Textile Mill Products	------
25	Lumber and Wood Products	-----

transfer, often producing the hot water, while direct combustion is used to produce hot air. The form of the energy used depends on the process and the kind of energy sources available. As shown in Figure 5-6, 7% of the energy consumed is less than 212°F, 23% is between 212 to 550°F and the remaining 70% is over 550°F.

Not all low-temperature industrial requirements need to be met with primary energy, i.e., fuel which is burned to produce the low-temperature heat. The requirements can often be met through conservation and improved energy management. Since most of the previously mentioned studies were completed, industry has undertaken considerable conservation measures. Increased equipment and plant maintenance (such as better insulation, condensate return, cascading, cogeneration, and process changes which may eliminate the energy requirement all together) are a few of the ways industry has reduced their energy needs. Between 1972 and 1980, industry reduced per-unit-of-output energy consumption by a substantial 15.4% (U.S. Department of Energy, 1980). To what extent this has altered patterns of energy use or the distribution of energy use between low, medium and high temperature, has not been evaluated.

Low-temperature requirements exist in many industries, particularly if preheating of boiler feedwater is included (Appendix J, Section 3). Although there are a small number of low-temperature processes, they are found in many different kinds of manufacturing plants. Past industrial studies have focused on those industries which have high total energy use. In the future, industries with high percentages of low-temperature requirements but small consumption should also be explored. Small industrial consumers may well provide potential for near-term applications for solar technologies. Both large and small industrial energy users are essential for the fullest development of solar pond technology.

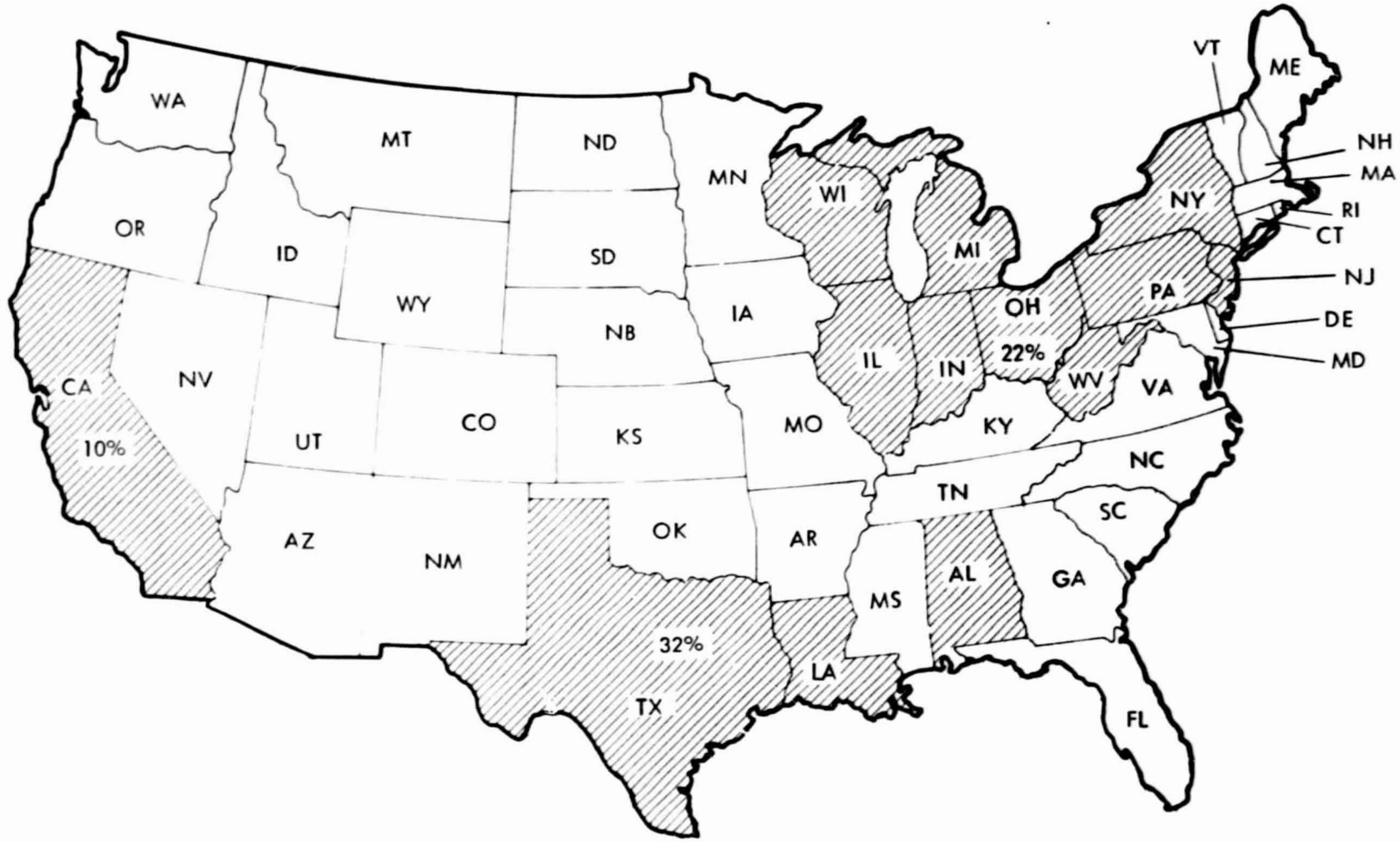
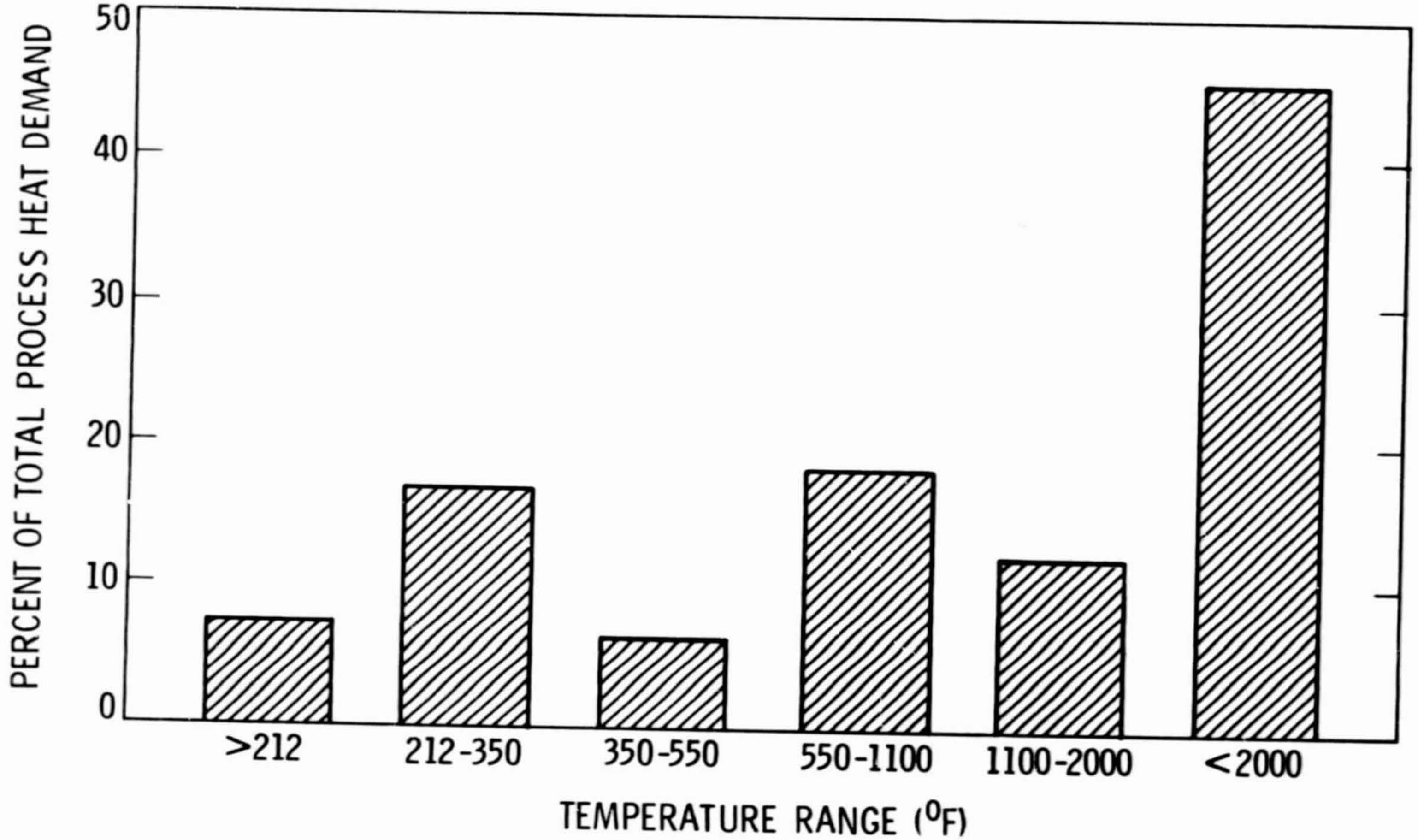


Figure 5-5. Regional Distribution of Industrial Energy Use. (Shaded area represents three geographical areas where over 60% of all U.S. industrial manufacturing is found.)



SOURCE: INTERTECHNOLOGY (1977)

Figure 5-6. Thermal Energy Consumption in Industry by End-Use Temperature

Of industrial energy demand in SIC Codes 20-39, 68% is for process heat (Brown, 1980), used as hot water, hot air, steam, or direct fire heat. About 3% (0.8 quads) used is less than 212°F. The percentage will be less for solar pond applications because 170 to 200°F rather than 212°F is the upper limit of heat delivered by solar ponds to the load.

Table 5-12 lists the industries having production processes whose energy requirements could be met by a solar pond. The majority are in the

Table 5-12. Industries with Thermal Processes Less Than 200°F[a]

SIC	Industry	Process	°F
20	Food Processing		
201	Meat Products	Scalding, clean-up	140-160
202	Dairy Products	Condensing, evaporation	160-200
203	Preserved Fruits	Drying, blanching, heating	160-200
204	Grain Mill Products	Drying, water heating	120
205	Bread and Baked Goods	Air heating	100
206	Sugar	Evaporation, heating	140-200
207	Fats and Oils	Drying, heating	120-180
208	Beverages	Washing, water heating	170
25	Furniture	Drying	150
26	Paper and Allied Products	Pulp refining	120
28	Chemicals		
282	Plastics, Synthetics	Washing, drying	120-200
283	Drugs	Heating	150
284	Soap	Various	180
29	Petroleum Refining	Oil tank heating	150
31	Leather	Tanning, drying	80-140
32	Stone, Clay and Glass		
327	Concrete, Gypsum	Hot water, block curing	120-190
33	Primary Metals		
332	Iron and Steel Foundaries	Pickling	110-212

[a]This represents only the selected industries with low-temperature process heat requirements.

food processing industry, with the rest scattered throughout several industries. Low-temperature energy is used for heating water for washing, rinsing, plating and storage tanks; baking; process mixing and steam generation for vats, cookers, milling; and boiler feedwater or make-up (Wilson, et al, 1980).

Food processing is by far the largest single consumer of low-temperature energy in the United States: nearly 294 trillion Btu or roughly 47% of all the low-temperature energy. As shown in Table 5-13, chemicals and paper follow, consuming 143 and 120 trillion Btu, or 23 and 19%, respectively. The remaining four low-temperature thermal energy industries (primary metals; furniture; stone, clay and glass; and leather) consume the remaining 11%. Overall, 630 trillion Btu are consumed in the United States under 200°F. Although this is an imprecise number, it is within 10% of the results of the 1980 SERI solar ponds study (Jayadev, 1980).

5.2.3 Pond-related Characteristics of Industrial Processes

5.2.3.1 Food Processing (SIC 20). Food processing is the largest low-temperature energy consumer. This industry uses most of its energy under

Table 5-13. Ranking of U.S. Industries By Low-Temperature Energy Use (10^{12} Btu)[a]

Industries	200°F Energy Use	Top State Consumers
Food Processing (SIC 20)	293.8	California, Illinois, Iowa
Chemicals (SIC 28)	142.6	Texas, Louisiana
Paper and Allied Products (SIC 26)	120.4	Wisconsin, Alabama, Georgia
Primary Metals (SIC 33)	30.9	Pennsylvania, Ohio, Indiana
Furniture (SIC 25)	17.7	South Carolina
Stone, Clay and Glass (SIC 33)	15.8	Pennsylvania, Ohio, Texas
Leather (SIC 31)	9.2	Wisconsin, Massachusetts, Pennsylvania
Total	630.4	

[a]This represents only the selected industries with low-temperature process heat requirements.

350°F, with a significant portion under 200°F. Meat packing and dairy products are two processes where over 50% of the IPH requirements are less than 200°F. Although food processing meets many criteria for applicability of ponds, two factors should be considered: Food processing firms tend to be near their markets for ease of product delivery, so many firms are in urban areas where sufficient land area is not likely to be available. In addition, certain food processing operations and their energy demands are seasonal, which may increase a firm's resistance to new, capital-intensive investments because of the shorter period over which the costs can be amortized.

Food processing, however, is the only SIC Code category found in all states of the country. Even though Alaska's and Puerto Rico's consumption are not shown because the quantity of energy consumed is not statistically significant, food is grown and harvested there also. As shown in Table 5-14, over half of the total low-temperature thermal energy consumption in the food processing industry is within the Great Lakes region (125 trillion Btu). On a state-by-state basis, however, California is the largest single food processing state, followed by Illinois and Iowa. Details of state energy consumption by SIC Code can be found in Appendix J, Section 1.

SIC Code 207, Fats and Oils, also offers an opportunity for a solar pond application (Barbieri, et al, 1978; French and Barbiera, 1978). Although the thermal energy requirements have not been quantified in this study because of insufficient data, the temperature requirements are within the range of a

Table 5-14. Regional Distribution of 1976 Thermal Energy Use Less Than 200°F (10^{12} Btu)[a]

Region	SIC Code Category							
	20	23	26	28	31	32	33	Total
Great Lakes	125.0	3.9	31.2	22.0	2.9	4.6	19.4	209.0
Tennessee Valley	27.9	8.0	13.9	46.3	0.3	3.4	2.3	102.1
Atlantic Northeast	31.3	3.1	26.3	21.7	6.0	2.2	4.2	94.8
Gulf Coast	23.1	0.8	36.8	25.0	0	1.7	2.3	89.7
Red River Valley	20.6	0.8	2.6	22.6	0	1.4	1.4	49.4
Southwest	20.6	0.9	1.8	2.8	0	0.9	0.7	27.7
Salt Lake	16.9	0	3.2	2.2	0	0.5	0.2	22.0
Pacific Northwest	14.4	0.2	5.6	0	0	0.8	0.4	21.4
Black Hills	13.4	0	0	0	0	0.3	0	13.7
Hawaii	0.6	0	0	0	0	0	0	0.6
Alaska	0	0	0	0	0	0	0	0
Puerto Rico	0	0	0	0	0	0	0	0
Total	293.8	17.7	120.4	142.6	9.2	15.8	30.9	630.4

[a]This represents only the selected industries with low-temperature process heat requirements.

solar pond and should be investigated in more detail. Large tanks are similar in size to oil storage tanks are used to store vegetable oil and must be heated prior to processing. Vegetable oils such as coconut oil and palm oil are brought in by tanker-car or ship, and pumped into holding tanks. Because many of these oils solidify at ambient temperatures, the oil must be heated in order to pump it into the plant for processing. Currently, the tanks are heated by circulating hot water through coils in the bottom of the tanks for approximately 2 days before pumping the oil into the plant. The temperatures required are 85 to 120°F depending on the type of oil being processed. As a year-round application, tank heating could provide a good market for solar ponds.

5.2.3.2 Furniture & Fixtures (SIC 25). SIC 25 uses little energy, but in certain manufacturing processes, all the energy consumed is less than 93°C. For both wooden (SIC 2511) and upholstered (SIC 2515) furniture, 150°F air is the only thermal energy requirement and is used to dry the wooden frames. Virtually all the furniture is manufactured in South Carolina.

5.2.3.3 Paper and Allied Products (SIC 26). Pulpers are machines in which pulp and water is heated to 120 to 150°F, mixed up, and then fed into the paper- or paperboard-making equipment. Steam is injected directly into the pulpers to create the 120 to 150°F required. In one paper mill steam injection accounted for 33% of the total energy consumed.

Paper and paperboard mills are located in a number of states. Wisconsin is the largest user of low-temperature process heat in this category, but the bulk of the production is in the southeast. Maine, Washington, and Pennsylvania round out the top 10 consumers in this industrial category. The urban location of many paper and paperboard mills, however, may reduce the feasibility of ponds because of land area constraints.

Pulp mills do not appear to be good applications of ponds. There are considerable waste by-products from the raw pulping process. With good conservation and utilization of this indigenous resource, little primary energy for low-temperature heat will probably be required. Pulp mills also tend to be located near their source of raw material, in wooded areas where the terrain may not be suitable for a pond. Only in isolated instances will this offer a good pond situation.

5.2.3.4 Chemicals and Allied Products (SIC 28). The chemical industry is the second largest consumer of low-temperature heat, using 23% or 142.6 trillion Btu in 1976. It has three processes where low-temperature heat is used: the production of plastic materials and synthetics, the production of drugs, and the manufacture of soaps, cleansers and toilet goods. The low-temperature energy generally is supplied as part of the steam boiler operation, or as heated air for drying processes.

Although over 40% of all chemical manufacturing is in Texas and Louisiana, those chemical manufacturers that produce products using low-temperature thermal energy are found relatively equally distributed between Texas, Tennessee, Virginia, South Carolina and states of the Atlantic Northeast.

The chemical industry has expressed an interest in solar ponds for two reasons: One, they have many existing ponds which might be converted to or used as solar ponds; two, they often have significant amounts of land around their plants even in an urban area, from the buffer zone often required between the plants and surrounding neighborhoods.

5.2.3.5 Leather (SIC 31). Like furniture manufacturing, leather and leather products (SIC 31) are a small energy user within the total industrial sector. They consume roughly 1% or 92 x 10^{12} Btu/yr of low-temperature process heat. However, over 60% of the thermal energy they consume is less than 200°F. There are only a few pockets of production, primarily in Wisconsin, Pennsylvania and Massachusetts. Manufacturing tends to be in SMSAs. Although energy costs may be high in the areas where leather goods are manufactured, insolation levels are not. However, Leather Products is a highly competitive industry and faces a great deal of overseas competition. If a near-term, low-cost application for ponds can be found, it could benefit the industry.

5.2.3.6 Stone, Clay and Glass (SIC 32) and Primary Metals (SIC 33). SIC 32 and 33 are two of the highest energy consumers in the industrial sector. In both cases there is a tremendous amount of excess heat from higher temperature that could be recovered and used to meet low-temperature requirements. However. there are particular products which could be good candidates. SIC 2271 uses hot water at 180°F for curing concrete blocks, and SIC 2273 uses hot air for drying aggregate for ready-mix concrete. Both tend to operate away from the high-temperature facilities. They are both small consumers of energy compared to their industry as a whole. Much of their production appears to be outside SMSAs and thus should have land area available. Although a significant portion of both industries is found in the Great Lakes region where insolation levels are not as high, there is a large concentration also found in California and Texas.

Finally, pickling of steel and iron (SIC 33) offers a good pond application, but like stone, clay and glass (SIC 32), there are high-temperature processes available. The real potential needs to be further investigated. This industry is heavily concentrated in the urban areas of the Great Lakes and Atlantic Northeast regions. Consequently, land availability may preclude any substantial solar pond use.

5.2.3.7 Other. Petroleum refining is another low-temperature application which appears to be highly suitable for solar ponds. However, in the literature there is no breakout or estimation of either the temperature required or the quantity of energy involved in this potential application. As with the vegetable oil tank heating, there is tank heating in the petroleum refining process. For certain types of crude oil, the oil needs to be heated to 150°F before it can be pumped. There is an excess of low-temperature heat in the petroleum refining industry because of the substantial amount of high-temperature energy used in the manufacturing process. If cascaded and the waste heat used, the higher temperature energy can provide all the lower temperature requirements. However, it appears that there are farms where a large number of oil tanks are kept. While excess energy is available at the

refineries, the tank farms are often remotely located. Consequently, they do not have access to the cascaded higher temperature thermal energy produced by the petroleum refining process itself. Therefore, solar ponds could provide a competetive energy source for tank heating.

There may be other industries with low-temperature demands. As one report found (Insights West, 1980) over 50% of the firms used hot water somewhere in their manufacturing process. However, the amount is often not significant enough to show up in normal data-gathering materials. As ponds become more widely used, previously undocumented applications will emerge.

5.2.4 Existing Ponds and Land Use

Existing ponds and land use are two factors which could heavily influence solar pond usage in industry. Land is a necessity for solar ponds. The present of existing ponds could also produce an economic incentive if there was potential to convert them to or use them as solar ponds.

5.2.4.1 Existing Ponds. To determine the magnitude of the potential existing pond resource, an Environmental Protection Agency (EPA) survey on waste disposal ponds or impoundments was utilized. As part of a study undertaken in 1977-78, this survey yielded data for the industrial, municipal, mining and agricultural sectors. It is the only known national assessment of existing ponds that has been undertaken, completed and documented by all 50 states. However, the EPA results are still under review and only rough data was obtained. California (Ling, 1978) and Nevada (State of Nevada, 1979) were the only states with information available in any detail. Thus, there were insufficient data to determine the size of the existing ponds, the amount of discharge into them, the chemical content of the liquid, whether they were still in use or abandoned, and many other factors. However, the results do show that there are tremendous numbers of existing ponds or pond sites spread through all industries. They could be an important factor to a particular firm in assessing feasibility of solar ponds.

According to the EPA data, 176,500 impoundments used to hold liquids were in existence at nearly 77,800 different sites in 1977-78. The average number of ponds per site is 2.3. Table 5-15 lists the impoundments by sectors of the economy. Nearly 37% of all impoundments are in the oil and gas industry followed by 21% in the municipal and nearly 15% in the industrial sector. However, the EPA classifications do not coincide with the previously used Census of Manufacturers information. Some of the oil and gas industries would fall within the Census Bureau's mining sector and others within the industrial sectors. However, interpreting the data loosely we can see that a sizable number of ponds are within the industrial sphere, which includes both mining and industrial manufacturing. Industrial mining and oil and gas impoundments constitute nearly 65% of all waste disposal impoundments.

EPA also identified over 4,700 abandoned ponds. The vast majority of these (70%) occur within the same three industrial, mining, and oil and gas categories. This could be potentially beneficial to solar pond development, in that an abandoned pond might easily be converted without disturbing the actual operation of a firm. But without knowing the contents of the abandoned

Table 5-15. Existing Impoundments by Economic Sectors

Sector	Number of Impoundments	Percentage of Total
Agriculture	19,169	10.9
Municipal	36,179	20.5
Industrial (Manufacturing)	25,820	14.6
Mining	24,451	13.9
Oil and Gas	64,951	36.8
Other	5,745	3.3
Total	176,315	100.0

ponds, their ownership status, and their specific locations vis-a-vis the plant site, it is difficult to know the extent of this resource.

On a state-by-state basis, four states have almost half the waste disposal ponds in the United States (45%) (Table 5-16). Of these, Pennsylvania has the greatest number and has nearly twice as many as New Mexico, Ohio, or Texas, the next three states. The largest use for these ponds is in oil and gas and mining. On a regional basis, five of the top 10 states occur in the sunbelt regions: New Mexico, Texas, California, Arkansas, and Florida. Many of these ponds are for mining or oil and gas production. As with existing ponds in general, the extent to which any of these ponds could be converted to or used as a solar pond installation is not known. The magnitude of the potential land area involved in existing and abandoned ponds, however, is significant enough and dispersed enough throughout industry that further investigation is warranted.

5.2.4.2 Land Use. Solar ponds are land-intensive and, unlike other solar technologies, require flat land area. Without investigating every firm in the industrial sector, there is no way to determine the total amount of flat-land area available near a particular manufacturing process. However, land is more likely to be available to industries located outside of urban areas. Examination of low-temperature energy use by region and by use inside or outside SMSAs leads to some suggestions as to where solar ponds may have greater potential.

Energy consumption data is collected by Standard Metropolitan Statistical Area. Low-temperature energy not consumed within a SMSA is assumed to be consumed in a non-SMSA. As shown in Table 5-17, 57% of all low-temperature energy is consumed in non-SMSA areas with the remaining 43% within SMSAs. For all but four regions, over 60% of the low-temperature energy is consumed in non-SMSA areas. Of the four with energy consumption

Table 5-16. States Having the Largest Number of Ponds

State	Number of Ponds	Dominant Type of Ponds
Pennsylvania	34,224	60% - oil and gas; 16% - mining
New Mexico	17,746	86% - oil and gas
Ohio	16,357	77% - mining
Texas	10,740	51% - oil and gas
California	7,577	45% - municipal; 27% - oil and gas
Arkansas	6,806	84% - oil and gas
Illinois	6,677	46% - oil and gas
Florida	5,610	63% - municipal
Missouri	4,683	45% - agricultural; 44% - municipal
Oklahoma	4,538	49% - oil and gas; 30% - municipal

greater in SMSAs, three of the regions (Red River Valley, Southwest and the Salt Lake) have highly dense urban areas surrounded by large areas of less developed land. Therefore, it is conceivable that even though the energy consumption is higher within the SMSAs in these three regions, the density of surrounding land may be low enough that land area may be available for ponds.

In the Atlantic Northeast only 39% of the energy is consumed in non-SMSA areas. Being the most heavily populated area in the United States, it is more likely that there would not be available land area for any sizable usage of solar ponds.

The Gulf Coast region has the greatest percentage of energy consumed in non-SMSA areas. In addition, it has areas of high insolation. It could have a fairly high potential for solar pond development.

The Pacific Northwest and Black Hills also have over 70% of their low-temperature thermal energy consumption in non-SMSA areas. Because the Black Hills region has little dense urban development, solar ponds should find little difficulty in being accepted if insolation and other economic factors were favorable.

In the Pacific Northwest, another situation occurs. The greatest percentage of energy is consumed in food processing and the paper industries. Although there is poor insolation in the western areas of Washington, Oregon and Idaho, and the terrain is heavily wooded and mountainous, these areas warrant further investigation. For example, the eastern half of Washington and Oregon and the southern part of Idaho are basically high plains or semi-desert. They have a relatively high level of insolation, and also a sizable amount of food processing. With changes occurring in the price and

Table 5-17. Regional Distribution by SMSA/Non-SMSA of 1976 Thermal Energy Use, 200°F in 10^{12} Btu[a]

Regional	SMSA	non-SMSA	Total
Great Lakes	80.8	128.2	209.0
Tennessee Valley	38.3	65.0	103.3
Atlantic Northeast	58.2	36.6	94.8
Gulf Coast	22.8	67.2	90.0
Red River Valley	26.7	22.7	49.4
Southwest	20.6	7.1	27.7
Salt Lake	15.9	6.1	22.0
Pacific Northwest	6.2	15.2	21.4
Black Hills	3.5	10.2	13.7
Hawaii	0.2	0.4	0.6
Alaska	0	0	0
Puerto Rico	0	0	0
Total	273.7	358.7	631.9

[a]This represents only the selected industries with low-temperature process heat requirements.

availability of alternative forms of energy, solar pond development may have significant future potential.

Both the Great Lakes and Tennessee Valley regions have just a little over 60% of their energy consumed in non-SMSA areas. The nature of the specific terrain varies considerably in this region as does the level of insolation. It is much more difficult to estimate the land availability here.

Certain industries tend to be located mostly in SMSA or mostly in non-SMSA areas. For example, primary food processing such as fruit drying occurs in agricultural areas, close to the raw materials. Secondary processing such as preserves, bread and bakery products, milk pasturization and fluid milk processing, tend to be located in urban areas near their markets. Although a significant portion of stone, clay and glass (SIC 33) and primary metals (SIC 32) are located in urban or urban fringe areas, those industries with low-temperature energy requirements, e.g., concrete block curing and foundaries, are often in non-SMSA locations.

Like the food processing industry, the paper industry (SIC 26) has both SMSA and non-SMSA processing. The primary processing of the wood products occurs in non-SMSA areas. This portion of the manufacturing process

also consumes the least amount of low-temperature energy, and is located in terrain unsuitable for solar ponds. Secondary processing plants where paper products are manufactured, e.g., tissue paper, boxes, and paper towels, tend to occur in SMSA areas. Like the food processing industry, these are located near the markets for their products. Chemicals, furniture, and leather do not appear to be biased toward urban or non-urban areas. The furniture industry is located near its raw materials which are found in South Carolina. Leather is more of an urban industry and therefore tends to be within SMSA areas. The chemical industry tends to be heavily concentrated, particularly in Texas and Louisiana, and no particular SMSA/non-SMSA bias appears to exist.

Lawrence Livermore Laboratory (LLL) surveyed the impact of land use on solar industrial process heat for the food processing industry (Casamajor, 1980). The LLL study examined land use of 1330 food processing plants in the far western United States (Arizona, California, Hawaii, Oregon and Washington) to determine the available surface area of each plant and assess each plant's potential for solar energy utilization. LLL was able to identify those industries having the highest potential for applying solar energy to their process heat loads. The study included manufacturing processes with temperatures under 350°F.

Although the results of the LLL study cannot be applied nationwide and did not concern solar ponds specifically, they give a good sense of the land area problem. LLL determined that about 25% of the energy used for food processing in the study area could be supplied by solar if all the available surface area at and adjacent to the plants was devoted to solar collectors. Table 5-18 lists the top 10 potential 4-digit SIC Code groups that appeared to

have sufficient land area to provide at least 25% of their energy requirements with solar. As Table 5-19 shows, over 50% of the plants had sufficient surface area to meet at least 50% of the total thermal energy requirements, i.e., those under 350°F. Direct comparisons cannot be drawn to solar ponds from this study because roof area is included as well as south facing, sloping land. However, the study somewhat supports the arbitrary SMSA/non-SMSA bifurcation used in this report.

5.2.5 Regional Summary

The regional distribution of low-temperature energy use in industry corresponds heavily with the overall geographical location of total industrial energy use, but there are some differences. Whereas 64% of all industrial energy is consumed in three regions of the country (see Figure 5-5), over 73% of all low-temperature energy is consumed in those same geographical areas (Figure 5-7). In addition, states such as Minnesota, Iowa, West Virginia, and the Gulf Coast states, also are large consumers of low-temperature thermal energy.

The two regions which consume nearly 50% of all low-temperature energy are the Great Lakes and Tennessee Valley regions (see Table 5-14), which include 16 states. Virtually all industries with low-temperature energy requirements are found in these two regions. States with the largest concentration of low-temperature requirements are Illinois, Michigan, and Pennsylvania, followed by New York and Ohio. In the Great Lakes region, food processing

Table 5-18. Top 10 SIC-Groups That Have Sufficient Land For Solar Development in the Far Western U.S. (LLL Study)[a]

SIC	No. of Plants	Annual Energy Consumption (10^{12} Btu)	Acres of Clear Surface	Description
2033	62	4.45	489	Canned fruits & vegetables
2063	4	2.89	442	Beet sugar
2034	21	2.46	300	Dehydrated fruits, vegetables, soups
2011	57	1.60	225	Meat packing plants
2037	37	1.83	209	Frozen fruits & vegetables
2084	27	1.21	184	Wines, brandy & brandy spirits
2051	65	1.51	175	Bread, cake & related products
2026	52	1.62	166	Fluid milk
2099	40	1.20	159	Food preparations, N.E.C.
2086	80	0.96	143	Bottled & canned soft drinks

[a]Source: Casamajor, 1980.

Table 5-19. Overall Solar Fraction (LLL Study)[a]

Limits on Solar System Size	No. of Plants	Energy Consumption 10^9 Btu	Solar Contribution 10^6 Btu	Collector Area (acres)
No limits	520	17.5	10.0	1,266
50%-99%	145	6.8	3.2	372
25%-49%	134	6.4	1.8	183
25%	533	33.5	1.8	217
Total	1332	64.2	16.8	2,038

[a]Source: Casamajor, 1980.

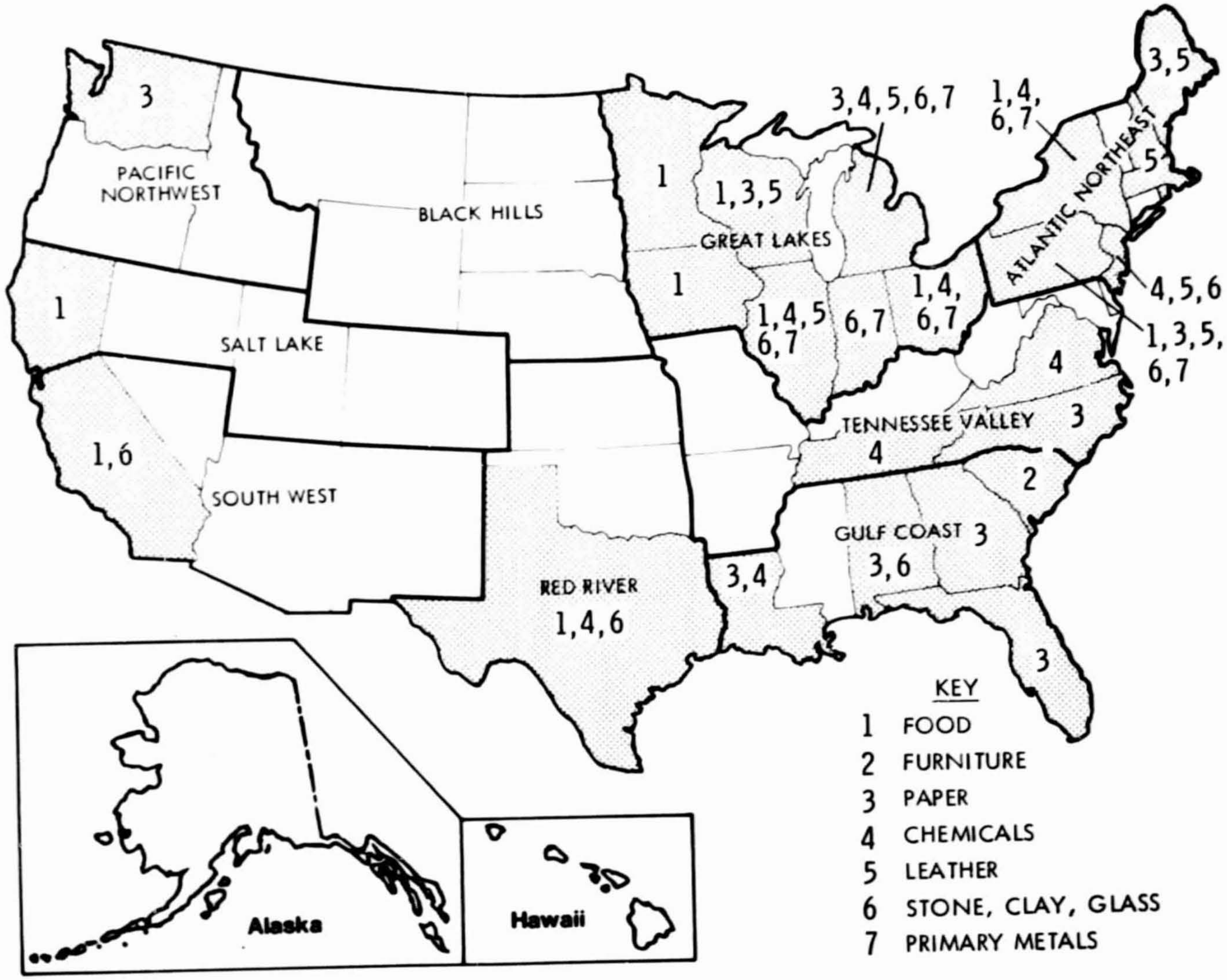


Figure 5-7. Regional Location of Low-Temperature IPH Use

(SIC 20) is the largest energy consumer. Within the Tennessee Valley, the greatest percentage of energy is consumed in the chemical industry (SIC 28) followed by food processing (SIC 20) and paper and allied products (SIC 26).

In the Atlantic Northeast, which also includes Vermont, New Hampshire and Maine, food processing (SIC 26), paper and allied products (SIC 26) and chemicals (SIC 28) fairly evenly comprise the three largest energy users.

Within the Gulf Coast region, the energy also is consumed in three major SIC Code categories: food processing (SIC 20), paper (SIC 26) and chemicals (SIC 28). Chemical processing occurs primarily in Louisiana. The remaining areas are primarily paper and paper-products processing.

In the Red River Valley, Texas has the most industrial activity of the three states. At the total thermal energy consumption level, Texas uses the greatest amount of energy in chemical production. At the low-temperature range, food processing (SIC 20) and chemicals (SIC 28) are almost equal. Together they comprise over 90% of all the energy consumed in this region.

In the remaining regions of the country (Southwest, Salt Lake, Pacific Northwest, Black Hills, and Hawaii) food processing (SIC 20) is the largest single consumer of low-temperature thermal energy. The one exception is in the Pacific Northwest, where paper and allied products (SIC 26) consume a sizable portion of low-temperature energy as well.

As stated earlier, Alaska and Puerto Rico also have food processing. However, the amount of energy consumed in industry in those two regions is not statistically significant and hence has not been included in this report.

In summary, 630 trillion Btu of low-temperature energy was consumed in 1976 in the industrial sector (see Tables 5-14 and 5-17). Of this amount, 57% is urban (273.7) and 43% is rural (358.7). Roughly 50% is consumed in two regions of the country: the Great Lakes and the Tennessee Valley. In those areas, over 60% of the low-temperature energy is in non-SMSA areas. However, specific terrain and topological characteristics may reduce the amount of potential area that would be usable for solar ponds.

The areas of highest insolation are the Southwest and the Red River Valley. In these areas food processing, stone, clay and glass, and chemical processing are the primary industries. If the next area of higher insolation is included, the Gulf Coast and paper and furniture manufacturing have potential.

Food processing and chemicals together account for 70% of low-temperature thermal energy consumption in the United States (see Table 5-13). Those industries are concentrated in California and Texas. When the areas of next higher insolation are included, the third highest low-temperature energy-consuming industries are included. These top three industries account for 89% of the low-temperature energy and all have sections of concentration in areas of high insolation. Given the results from the Lawrence Livermore Laboratory study on land use in the food processing industry, and data presented in the foregoing sections, one scenario for early solar activity in

the industrial sector is to focus on the food processing, chemical and paper products industries in the Southwest, Red River Valley and Gulf Coast regions. In addition, nearly half of the existing impoundments can be found in the regions of highest or next highest insolation.

Like any other solar thermal resource, solar ponds will probably find their early markets in areas of high insolation. Early industrial sector activity will probably occur in California, Texas, Louisiana and some of the Gulf Coast states, in the food processing or chemical industries. Although a small energy consumer, the furniture manufacturing industry in South Carolina should not be ignored; because all of the energy it consumes is under 200°F, offers a prime target for the low-temperature energy generated by a solar pond.

5.3 AGRICULTURAL PROCESS HEAT SECTOR

5.3.1 Introductory Remarks

The United States is indisputably the world leader in agricultural production. This enormous production, combined with the highly mechanized agricultural operations, results in considerable energy consumption for agricultural purposes. According to statistics, the 1977 agricultural energy consumption was about 3% of the total national energy consumption. The types of energy used in agriculture includes electricity, natural gas, LP gas, fuel oil, diesel oil, gasoline, and coal.

Agricultural energy is used in two major categories: crop operations and livestock operations. The total U.S. agricultural energy use for each state and each market region are shown in Table 5-20 according to fuel types and total Btu value (Federal Energy Agency, 1976; Federal Energy Agency, 1977). The total Btu value amounts to 2.014×10^{15} Btu/yr. The energy use related to crops only and livestock only are similarly shown in Appendix K; their Btu values are 1.790×10^{15} Btu/yr and 0.224×10^{14} Btu/yr, respectively. In each category, there are several different operations, and each consumes different types of energy. Some can possibly be replaced by solar pond energy; others cannot be.

The energy needs that could possibly be supplied by solar ponds for each category will be identified here, and the details of their applications and market sizes will be presented in the subsequent sections.

The crop operations category includes planting, fertilizer-related activities, irrigation, harvesting, crop drying, greenhouse operations and many others. Those suitable for energy supplies from solar ponds are the following:

(1) Crop Drying. Crop drying requires low-temperature thermal energy for the removal of moisture from the crops.

(2) Irrigation Pumping. Irrigation is mainly the pumping of surface or underground water; therefore, solar pond thermal energy generally has to be converted into either shaft power or electricity before it can be used to serve irrigation purposes.

Table 5-20. Agricultural Energy Consumption: Agriculture (Total)

Regions/States	Energy Use and Fuel Types							
	Gasoline, 10^3 gal	Diesel, 10^3 gal	LP Gas, 10^3 gal	Fuel Oil, 10^3 gal	Natural Gas, 10^6 ft^3	Coal, ton	Electricity, 10^6 kWh	Total, 10^9 Btu
Pacific Northwest Region	77128	173817	194387	15407	1442	24	7383	86975
Washington	4300	31742	7297	7954	318		3948	37571
Oregon	30731	23670	6504	7453	232		1698	20991
Idaho	42097	41277	6769		892	24	1731	28413
Salt Lake Region	153220	145011	25009	24947	8673	1984	3769	91719
Northern California	78685	83092	12470	24256	2867		2665	54918
Northern Nevada	4149	4265	995		52		201	2160
Utah	14831	11817	3014		322	1984	391	6936
Colorado	50136	45838	8531	691	5437		513	27635
Southwest Region	133862	123197	32908	30219	32887	19	5526	12119
Southern California	78685	83092	12470	24256	2867		2665	54988
Southern Nevada	4149	4265	995		52		201	2160
Arizona	24181	16530	1301	5963	14676	15	2198	36162
New Mexico	26847	19310	18142		15297	4	462	27888
Black Hills Region	430670	487149	193757	43	13481	236	15679	240753
Montana	58538	29419	5861		334	41	260	23811
Wyoming	17576	14249	1758		122	10	227	7523
North Dakota	124088	98404	5793	3	111	45	185	43302
South Dakota	89022	104390	31326	15	150	140	246	37898
Nebraska	141446	240687	149219	25	12764		1280	128219
Red River Region	517106	379950	133793	10331	229018		2779	353000
Kansas	148982	136263	45002	15	21847		402	98457
Oklahoma	103933	62026	21462		6532		285	51327
Texas	264191	181661	67329	10316	66246		2092	203216

Table 5-20. (Cont'd)

Regions/States	Energy Use and Fuel Types							
	Gasoline, 10^3 gal	Diesel, 10^3 gal	LP Gas, 10^3 gal	Fuel Oil, 10^3 gal	Natural Gas, 10^6 ft^3	Coal, ton	Electricity, 10^6 kWh	Total, 10^9 Btu
Great Lakes Region	1367165	616061	553031	10838	3354	2573	5149	509739
Minnesota	244160	109489	89909	215	366	314	937	96458
Iowa	328274	164581	143390	186	549	249	1243	135043
Wisconsin	177800	45097	46578	170	410		1126	53898
Illinois	268529	129635	138738	122	325	391	704	123275
Michigan	85409	48629	21787	6405	383		356	37184
Indiana	143900	66999	73929	168	206	990	398	70436
Ohio	119093	51631	38700	3572	1115	629	385	53445
Tennessee Valley Region	465142	348285	325933	59314	4726	15090	1914	260414
Missouri	139758	75767	46097	254	453		464	63576
Arkansas	71302	94618	57400		2886		310	48232
Kentucky	59364	34449	15912	1351	238	568	227	26861
Tennessee	50444	37817	10668	521	318	916	165	24850
West Virginia	9129	4281	2817	833	7	1423	36	4367
Virginia	33328	27455	29635	8378	96	4898	166	72057
North Carolina	66060	56668	142808	47158	632	7285	380	55927
Maryland	25408	11526	13516	491	96		119	10257
Delaware	10349	5704	7080	318			47	4287

Table 5-20. (Concluded)

Regions/States	Energy Use and Fuel Types							
	Gasoline, 10^3 gal	Diesel, 10^3 gal	LP Gas, 10^3 gal	Fuel Oil, 10^3 gal	Natural Gas, 10^6 ft^3	Coal, ton	Electricity, 10^6 kWh	Total, 10^9 Btu
Gulf Coast Region	320595	358388	157319	141147	3618	7590	1362	211505
Louisiana	48003	68594	10537		2251		138	30567
Alabama	38589	37562	24011	426	203		184	23701
Mississippi	56679	70876	19792	503	333		179	37159
Georgia	68673	62624	54878	9466	718	7276	316	4203
South Carolina	29847	30232	26163	9259	73	314	117	20333
Florida	78805	88500	21998	121493	40		428	57706
Atlantic Northeast Region	191221	77693	38721	11639	719	5100	1303	72339
Pennsylvania	74030	32903	18681	2562	435	3780	459	28677
New Jersey	15078	6893	1758	58	1		50	5140
New York	74952	29002	11594	4291	283	1320	526	27437
Vermont	8555	1536	2322	27			87	3191
New Hampshire	1850	591	436	90			21	767
Massachusetts	4220	1894	985	721			35	1687
Connecticut	4049	1646	2004	139			43	1614
Rhode Island	507	169	97	15			4	202
Maine	7980	3059	844	3736			78	3264
Alaska Region	282	48	65	4			1	80
Hawaii Region	8976	6493	173	40			708	6511
Puerto Rico Region								
National Total	3698641	2638955	1481542	303929	164125	32725	32088	2014221

C-3

(3) Greenhouse Conditioning. Energy use in greenhouse conditioning is mainly heating, with a smaller portion in cooling and :eneral ventilation. Solar ponds can thus supply the or portion of this type of energy requirement.

In the livestock management category, feed handling, waste disposal, space and water heating, egg handling, and brooding are some of the operations requiring an energy supply. The following operations are suitable for an energy supply from solar ponds:

(1) Space and Water Heating. Use of energy in these two areas is similar to use in residential and commercial buildings; therefore, solar ponds might supply these energy needs.

(2) Brooding. The major energy need in brooding is to provide heating energy to maintain proper temperatures for the brooding process; solar pond thermal energy is suitable for this purpose.

(3) Waste Disposal. Waste handling and waste conversion or digestion both require an energy supply. The latter need is mainly thermal energy; therefore, it can possibly be supplied by solar ponds.

In addition, space and water heating for farm houses should be included as part of the agricultural energy market, as this can obviously be supplied by solar ponds.

5.3.2 Characteristics and Energy Requirements of Various Agricultural Operations

5.3.2.1 Crop Drying. To prevent crop spoilage during storage and shipment, the moisture content of all grains must be kept at a low level, normally between 14 and 15%. How this can be done depends on the crops. Some crops require artificial drying, while others can be dried when they are still in the field. According to the Council for Agriculture Science and Technology (1975), the degree of artificial drying required for some important crops is as follows: rice, 100%; corn, 70%; soybeans, 18%; sorghum, 10%; wheat, practically none. However, because of the difference in crop sizes, the main energy consumer in crop drying is corn, which consumes about 60% of the energy used in crop drying. Tobacco curing is also a significant energy consumer.

Although the methods of crop drying vary with the crops, there are common features. Because corn drying and tobacco curing are the two major energy consumers in drying, the methods employed in these two cases will be used to illustrate the general applications.

There are three standard methods of drying corn: in-storage layer drying, batch drying, and continuous flow drying. The drying is generally accomplished by the use of forced hot air heaters. Depending on the original moisture content, the methods of drying, and the stage of drying, the hot air temperature used ranges from only a couple of degrees above ambient to as high as 220°F; however, the temperature is most frequently between 110 and 140°F.

Tobacco is cured either by air or by flue curing. The former process normally uses natural weather conditions, occasionally heating the air 5 to 10°F above ambient. The flue curing process, usually done in barns, consists of three stages: "yellowing," "fixing the color," and "killing out." In the "yellowing" period, the temperature in the barns is kept between 90 and 100°F initially, then increased to 115°F in the last few hours. During the "fixing the color" period, the temperature is slowly raised to 120 to 125°F in the beginning and then is increased to 140°F near the end. In the "killing out" stage, the temperature is gradually raised to 170 to 180°F. Thus the thermal energy need of crop drying is within the range of a solar pond thermal energy supply.

The critical time for drying crops is immediately after harvesting; therefore, it is dependent on crops. However, most of the crop drying comes in late summer and in the fall. For instance, the corn harvest is typically from the first week in September to the third week in December. For tobacco curing, the drying period is mostly from August to November. Clearly, the time period in which crop drying is needed coincides with the time during which a typical solar pond has its largest thermal energy storage of the year.

Because the temperature of the thermal energy requirements for crop drying and the time of drying are both consistent with solar pond characteristics, it is most suitable for solar pond application. In addition, the application will be rather simple and direct. Its main requirement is a hot brine transport system and a heat exchanger to transfer the heat from the hot brine to the drying medium, usually air.

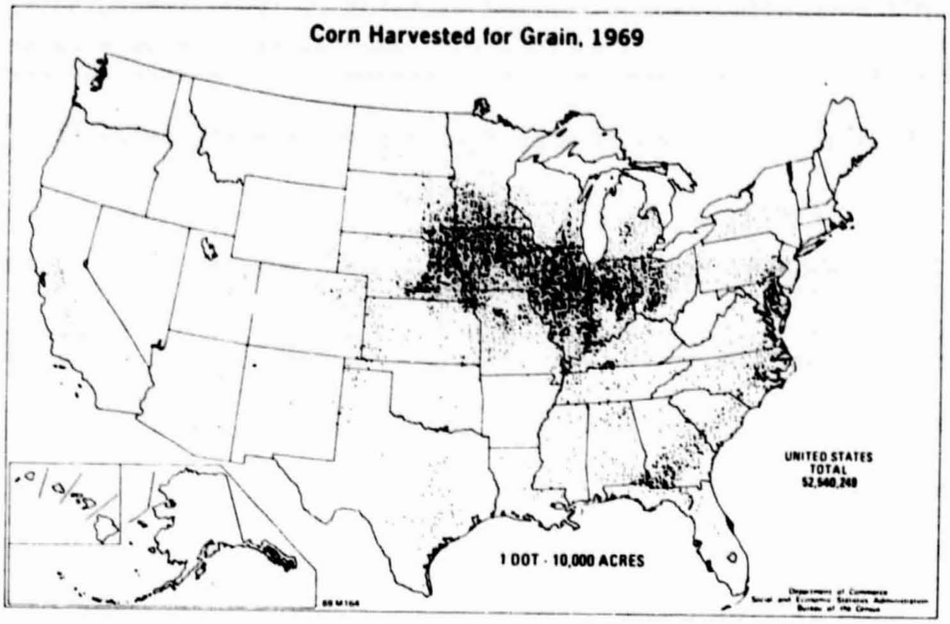
The regional and state energy needs for crop drying are tabulated in Appendix K for the types of energy used and the total Btu values. The total national consumption in 1974 was 0.1053×10^{15} Btu/yr. The Great Lakes region has the highest consumption, 0.3765×10^{14} Btu/yr, followed by the Tennessee Valley region with 0.2880×10^{14} Btu/yr.

The main fuel used in crop drying is LP gas, with a national consumption of 664.4×10^6 gal/yr, followed by fuel oil at 76.56×10^6 gal/yr.

Figures 5-8, 5-9, and 5-10 are maps showing the main production areas of corn, rice, and tobacco, respectively. All these require significant crop drying energy.

5.3.2.2 Irrigation Pumping. All plants require a water supply, but the amount of water required by croplands depends on the types of crops and the geographic conditions. Some crops require very little water; others need a tremendous supply. Figure 5-11 is a map showing the percentage of the cropland in each state of the country that needs irrigation. It is seen that in some areas practically all cropland has to be irrigated. Figure 5-12 shows the acreage that needs to be irrigated for various crops.

The energy needed for irrigation is mainly the pumping work necessary to move both surface and underground water. Some of the surface water is moved by gravity; other surface water requires very little pumping work, usually a lift of less than 20 ft. Underground water, on the other

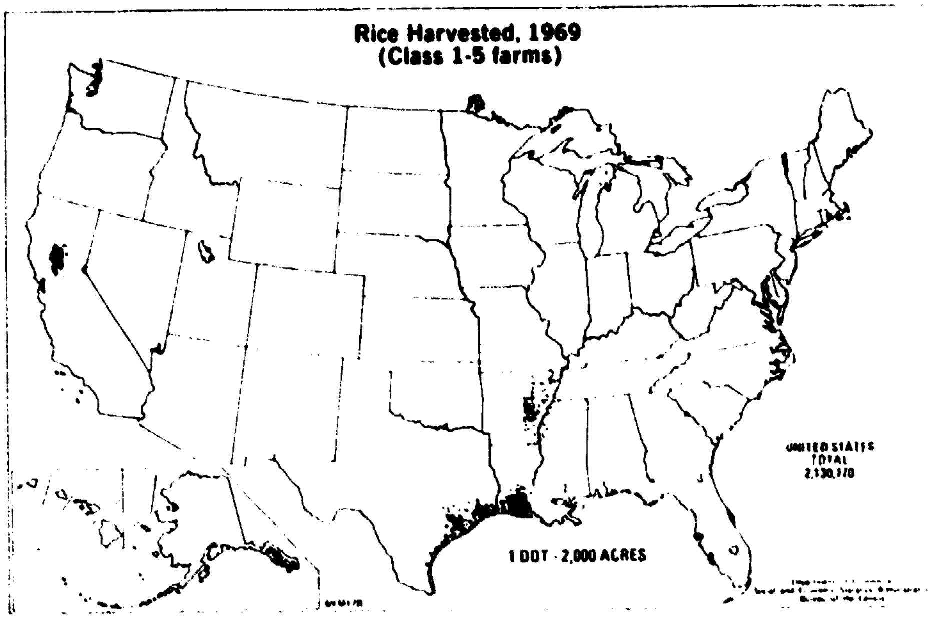


CORN ACREAGE PLANTED IN SELECTED STATES, 1973
(Estimated)

STATE	ACREAGE IN THOUSANDS	PRODUCTION IN MILLION BUSHELS
Iowa	11,800	1,204
Illinois	9,980	996
Nebraska	6,400	544
Minnesota	6,200	513
Indiana	5,400	534
South Dakota	3,760	142
Ohio	3,300	240
Wisconsin	3,200	173
Missouri	2,800	228
Michigan	2,100	134
Kansas	1,900	154
Georgia	1,840	80
North Carolina	1,550	114
Pennsylvania	1,490	81
Kentucky	1,160	86
New York	1,000	5

SOURCE: Agricultural Statistics, 1974, USDA, p. 29.
Preliminary data

Figure 5-8. Corn Harvested for Grain in 1969



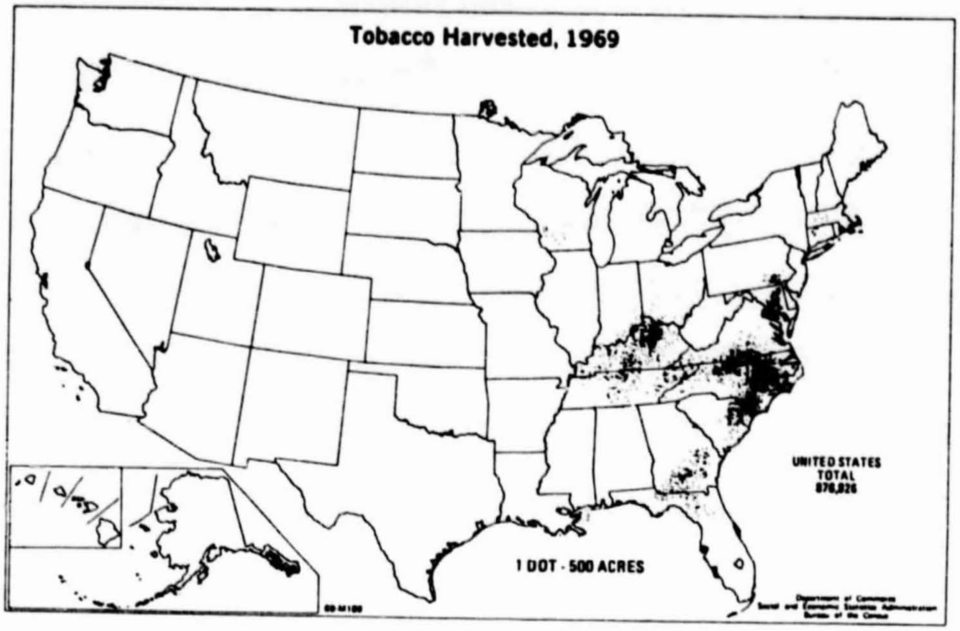
The acreage devoted to rice production in each state may be found in the table below.

RICE ACREAGE BY STATE, 1973
(Estimated)

State	Acreage in Thousands
Missouri	5.3
Mississippi	62
Arkansas	534
Louisiana	624
Texas	553
California	403
	(2,181)

SOURCE: Agricultural Statistics, USDA, 1974, p. 21.

Figure 5-9. Rice Harvested in 1964



TOBACCO: Acreage Harvested in Selected States, 1973, and Production (Estimated)

State	Acreage In Thousands	Production in Million Pounds
North Carolina	384	812
Kentucky	162	321
Virginia	74	138
South Carolina	67	132
Georgia	61	98
Tennessee	51	101

SOURCE: Agricultural Statistics, USDA, 1974, p. 100.

Figure 5-10. Tobacco Harvested in 1969

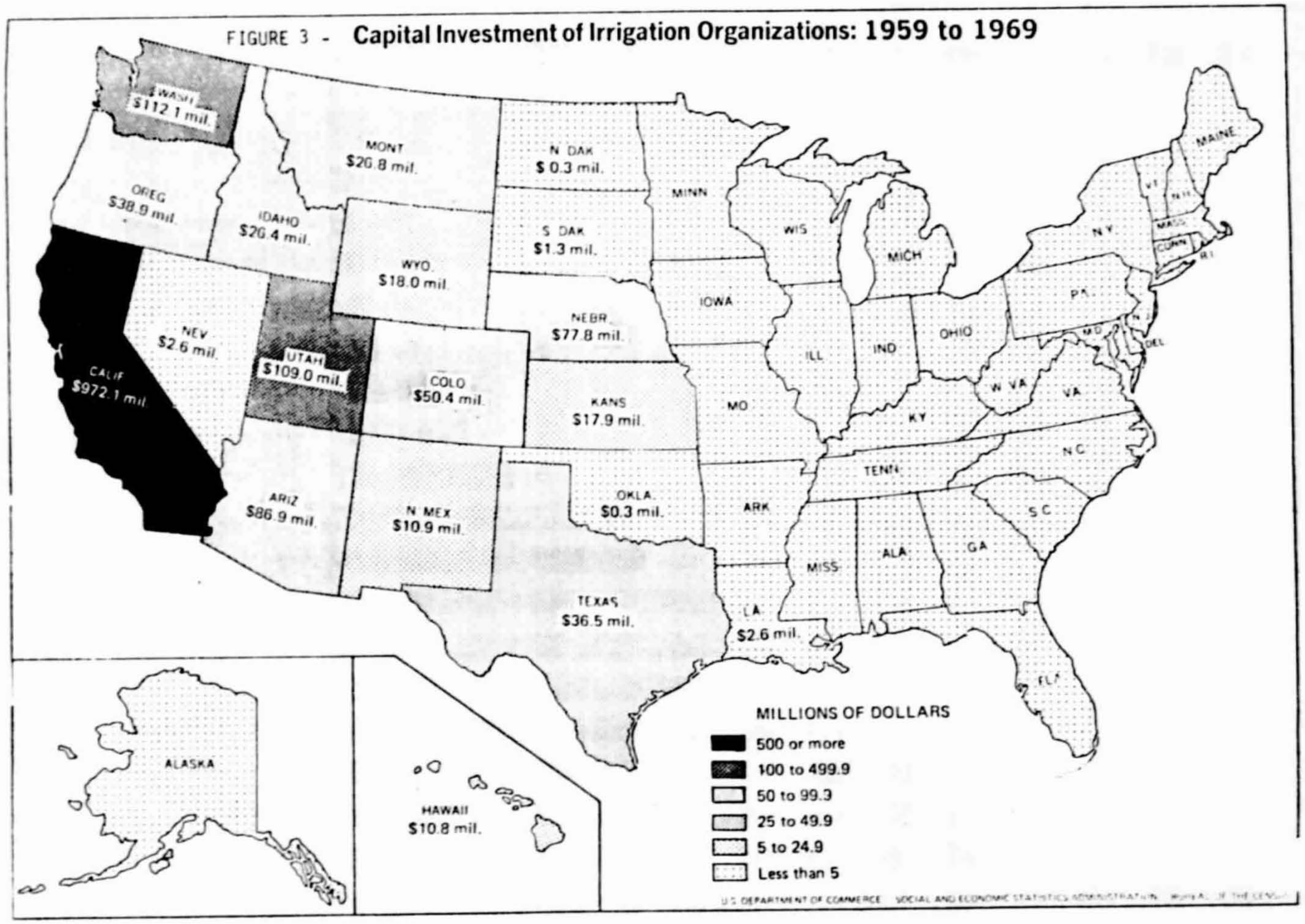


Figure 5-11. Irrigated Cropland Harvested as a Percent of Total Cropland Harvested in 1969

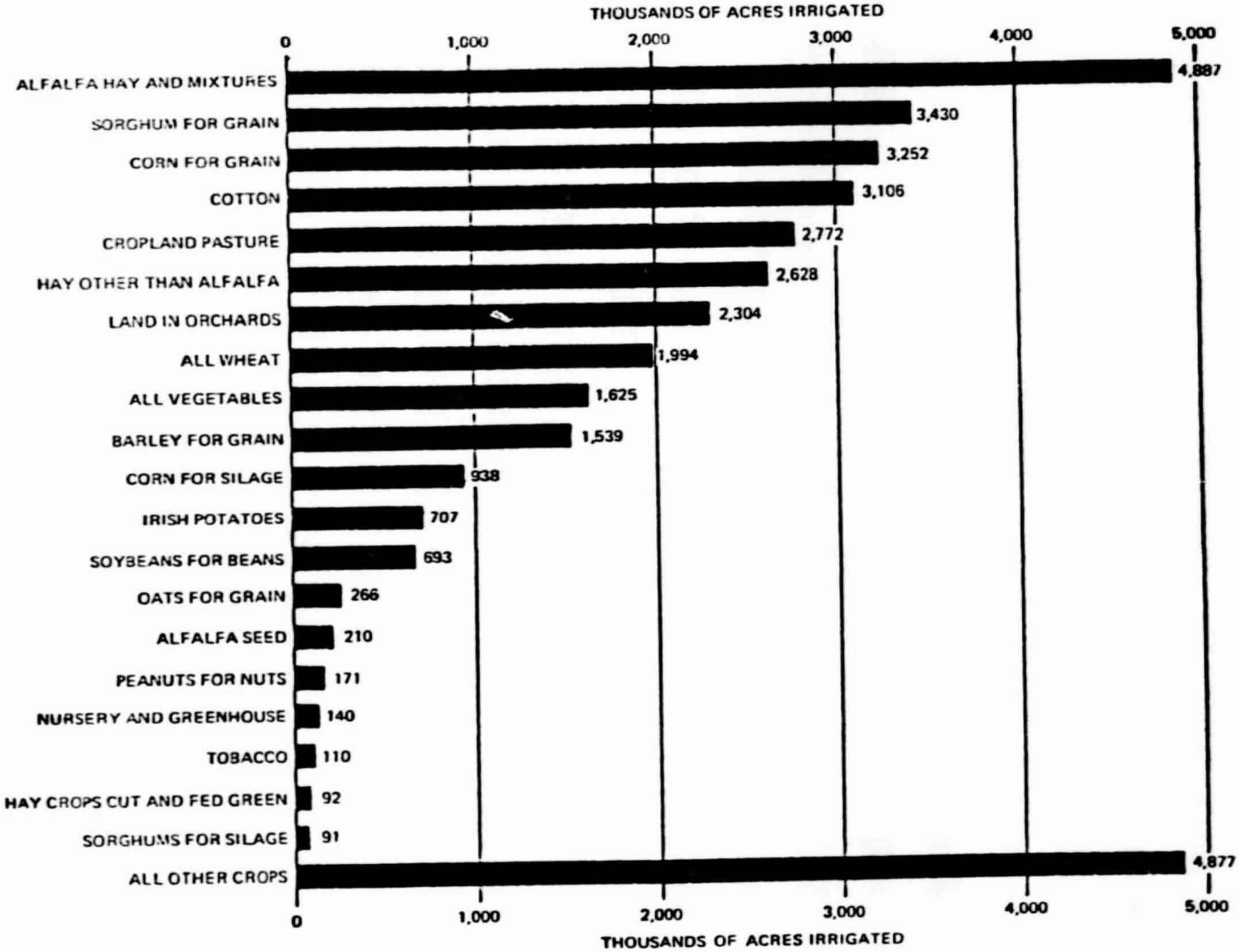


Figure 5-12. Irrigated Cropland in Specified Crops and Pasture on Class 1-5 Farms in 1969

hand, requires tremendous amounts of pumping energy, sometimes lifts of more than 300 ft. However, the average lift in the most extensive irrigation areas of the 17 western states and Louisiana is 169 ft (Douskin, Nichol and Heady, 1975).

Irrigation is required practically year-round, but the peak requirement is during the growing period of the hot summer months. Energy for pumping purposes is either by shaft power or electricity; therefore, a conversion scheme similar to an electric power generation system is necessary for a solar pond application.

The national, regional, and state energy consumption in irrigation for various fuel types and total Btu values is tabulated in Appendix K. The total national Btu value is 0.2607×10^{15} Btu/yr. The Red River region leads the country with a consumption of 0.1097×10^{15} Btu/yr, followed by the southwest region with a consumption of 0.5178×10^{14} Btu/yr.

Fuels used for irrigation purposes include gasoline, diesel oil, LP gas, natural gas, and electricity.

5.3.2.3 Greenhouse Conditioning. Environmental control, multiple cropping techniques, and the efficient use of water and fertilizers allow greenhouse operations to yield crops of three to more than 10 times the average for single-yield crops. For the same reasons, the operations are very energy-, labor-, and capital-intensive. However, greenhouse operations can generate exceptional values for fruits, vegetables, flowers, and other nursery crops that no other method can match. For this reason, such operations are becoming more popular and will eventually become an important agricultural enterprise.

Greenhouse operations need heating and a small amount of cooling and ventilation. Thermal energy from solar ponds can supply the majority of this energy, if some special heating system can be developed. Greenhouse heating has been done in various ways, ranging from the use of heaters to the use of piping systems carrying hot water or steam. To use a solar pond energy source, some of the old systems may have to be changed, while others require only the addition of a heat exchanger to transfer the heat from the hot brine to the heating media of the old systems. In general, both modifications in the old systems and the development of new systems are simple and straightforward.

Table 5-21 shows the regional greenhouse acreage and greenhouse numbers in 1970, and Table 5-22 shows the regional energy requirements. The estimated total national consumption in 1969 was 0.4085×10^{14}.

5.3.2.4 Livestock Management. Low-temperature heat (180°F) is required to heat animal shelters and to heat water for general animal care. The water heating need is rather steady throughout the year, while space heating will be concentrated in the cold winter months. Regional and statewide energy consumption for livestock shelter and water heating are shown in Appendix K. The total national consumption in 1974 was 0.15×10^{14} Btu/yr. The main fuel used is LP gas.

Table 5-21. Location of Greenhouse Production, 1970[a]

Geographic Division	Total Area Covered (ft^2)	Establishments
New England	18,929,562	762
Middle Atlantic	38,645,729	1,866
East North Central	61,986,698	1,940
West North Central	14,145,856	593
South Atlantic	26,452,593	903
East South Central	9,586,826	324
West South Central	8,970,564	368
Mountain	12,741,189	368
Pacific	81,690,923	1,386
	(Total: 6270.6 acres)	(Total 8,528)

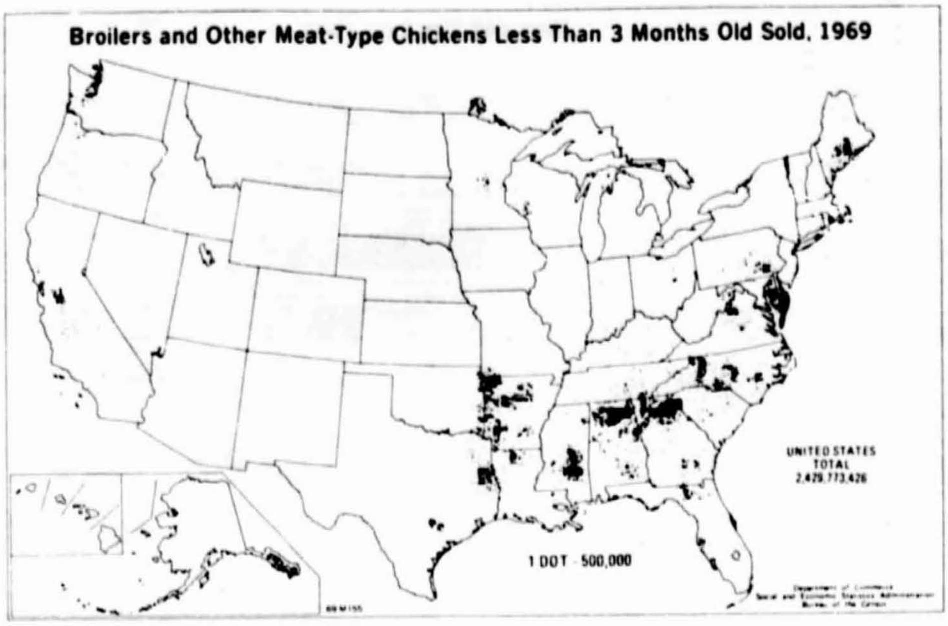
[a]Source: 1969 Census of Agriculture.

Table 5-22. Greenhouse Heating Requirements[a]

Zone	1969 Estimated Requirements from Fossil Fuels (Btu/yr) (10^{10})
Applachian	147.2
Corn Belt	1119.2
Delta States	39.9
Lake States	314.6
Mountain	127.8
Northeast	1281.2
Northern Plains	53.9
Southeast	168.2
Southern Plains	101.6
Pacific	731.3

[a]Source: 1969 Census of Agriculture

Most of the energy consumed in brooding is to condition brooding space, especially heating to maintain the necessary temperature and control the necessary humidity. Brooding of broiler-type chickens and of swine is probably the most energy-intensive. The energy need is year-round; however, because the main consumption is in heating, the amount required varies with the season and depends on the degree/day heating of the location. Figures 5-13 and 5-14 are maps showing the production areas of broilers, hogs and pigs. The regional energy consumption in livestock brooding is given in

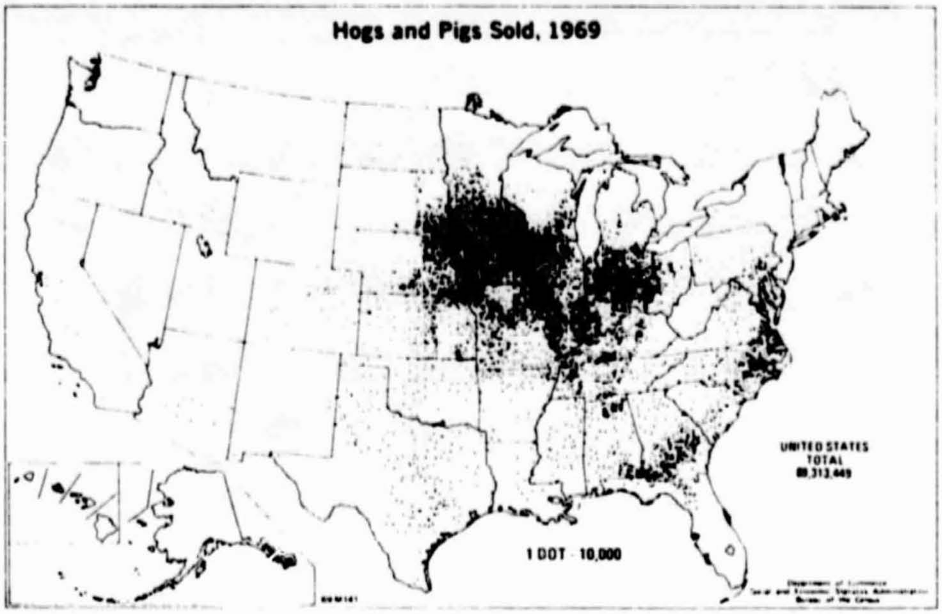


BROILER PRODUCTION IN SELECTED STATES, 1973[1] (ESTIMATED)

STATE	PRODUCTION IN MILLION POUNDS
Maine	318
Delaware	564
Maryland	744
North Carolina	1,133
Georgia	1,528
Alabama	1,438
Arkansas	1,756
Texas	641
California	341
Mississippi	885

[1] *Agricultural Statistics, 1974. Table 573, p 405.*

Figure 5-13. Broiler Production in 1969



HOG PRODUCTION IN SELECTED STATES, 1973[1]

State	Production in Million Pounds
Iowa	4,506
Illinois	2,705
Indiana	1,682
Missouri	1,498
Minnesota	1,327
Nebraska	1,179
Kansas	737
South Dakota	714
Ohio	691
North Carolina	593
Wisconsin	567

1 *Estimated Agricultural Statistics, USDA, 1974, Table 460, p. 319.*

Figure 5-14. Hog Production in 1969

Appendix K. The total national consumption in 19 was 0.24 x 10^{14} Btu/yr; the Tennessee Valley region led the country with a consumption of 0.8042 x 10^{13} Btu/yr, followed by the Gulf Coast region with a consumption of 0.6143 x 10^{13} Btu/yr. Fuels used for this purpose include LP gas, natural gas, coal, and fuel oil.

Livestock waste disposal consists of two major operations: handling the waste and the final disposal, such as digestion of the waste. The first operation is mainly mechanical work which may not be conveniently replaced by solar pond energy source. The second operation, depending on the nature of the disposal method, may need thermal energy at a relatively low temperature; therefore, it is possible to use energy from a solar pond. The energy consumption for livestock operation-related waste disposal is shown in Appendix K. The total national consumption in 1974 was 0.2 x 10^{14} Btu/yr. Gasoline is the main fuel used in this operation.

5.3.2.5 Farmhouse Space and Water Heating. The application of solar energy to space and water heating for farmhouses is appealing for two reasons: there is less concern for aesthetic aspects and "sun-rights," and solar energy could also be used in other farming-related operations as described elsewhere.

The estimated energy consumption for all occupied rural houses and for on-farm houses are given in Table 5-23 (U.S. Department of Commerce, 1972). The national total of the former is 1.73 x 10^{15} Btu/yr and 0.30 x 10^{15} Btu/yr for the latter. The regional distribution of all occupied rural houses is shown in Table 5-24.

5.3.3 Solar Pond Systems for Agricultural Applications

Figure 5-15 shows some of the agriculture-related energy use patterns. As can be seen, water heating energy demands remain about the same throughout the year, while grain drying requires energy only in the fall. Energy for space heating, such as for farm houses and animal shelters, is normally required in winter, while cooling energy requirements are mainly in summer. The energy requirements for greenhouse operations and livestock brooding are year-round but peak in winter, while irrigation energy needs peak in the summer.

Such differences in utilization patterns will affect the design of solar pond systems for agricultural applications; systems should ultimately be designed according to the specific application needs. However, for discussion purposes, the systems can be treated generally. Based on the possible application areas presented earlier, the main application will be in heating with possibilities in cooling and in generation of electricity. These will be discussed below, along with a total energy utilization concept.

5.3.3.1 Heating Systems. Water heating, space heating for farm houses and animal shelters, livestock brooding, greenhouse operations, grain drying, and waste disposal all require a heating system. The main components of a heating system should consist of a brine transport unit, a brine-to-working-fluid heat exchanger, and a hot fluid distribution unit.

Table 5-23. Estimated Energy Consumption for All Occupied Rural and On-Farm Houses (in 10^{12} Btu)

Fuel Type	All Occupied Rural Housing Units	On-Farm Houses
Fuel Oil, Kerosene	610	109
Utility gas	450	36
Liquified gas (LPG)	320	85
Electricity	160	25
Coal or Coke	100	23
Wood	80	19
Other fuel	7	1
None	4	1
Total	1,730	300

Table 5-24. Occupied Rural Housing Units

Region	No. of Units	% of Total
New England	808,694	5.1
Middle Atlantic	1,977,683	12.5
East North Central	2,962,309	18.8
West North Central	1,832,773	11.6
South Atlantic	3,242,822	20.6
East South Central	1,699,426	10.7
West South Central	1,602,209	10.2
Mountain	532,629	3.4
Pacific	1,111,441	7.1
Total	15,769,986	7.1

The brine transport unit should be rather standard; the choice of the heat exchanger, on the other hand, will depend on the working fluid used, such as water or air. The design of the distribution unit depends strictly on the application; for example, a unit for grain drying will be different from that of a greenhouse operation. The distribution unit may consist mainly of the existing heating system previously used with conventional fuels.

The design of the solar pond also depends on the energy utilization patterns of the application. The size of the solar pond and the depth of the storage zone will vary according to whether a steady, constant supply of thermal energy is needed, such as for water heating, or energy is only needed

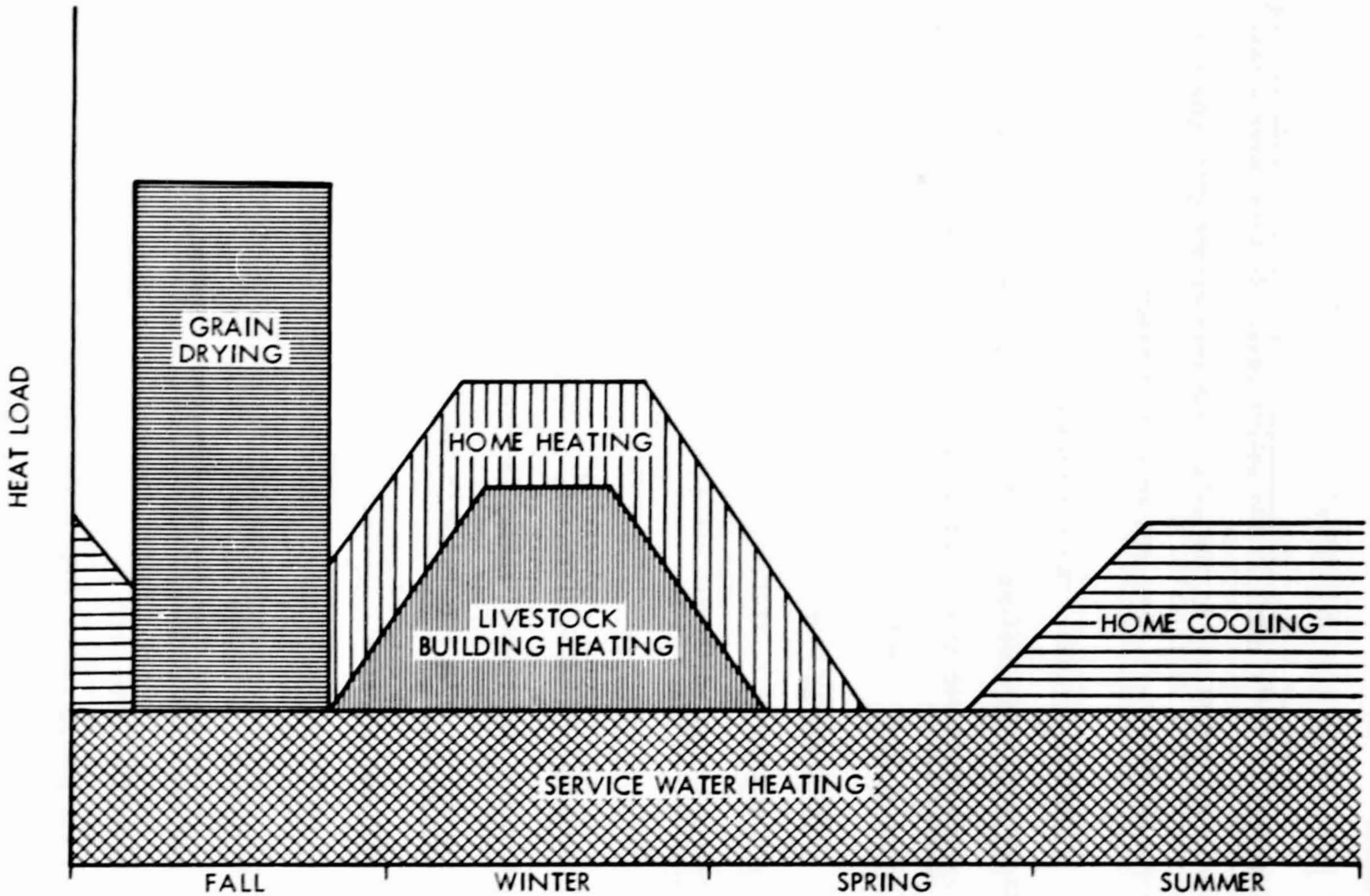


Figure 5-15. Representation of Farmstead Seasonal Demands for Heat Energy

in one season of the year, such as in the grain drying application. These factors must be considered along with insolation, energy loads and other fundamentals.

5.3.3.2 Electric or Shaft Power Systems. Lighting and irrigation require electric power, or shaft power in the latter case. In both cases a heat engine, normally an organic Rankine turbine, is needed to convert the thermal energy collected and stored by the solar pond into either shaft power or electric power. This application thus falls under the electric power generation application category and is treated elsewhere.

5.3.3.3 Cooling Systems. The requirement for cooling in agriculture activities is much less than heating requirements. The most likely applications are in the cooling of farmhouses, greenhouses, or possibly animal shelters. The demands will be concentrated in the hot summer months. A cooling system could use an absorption cooling system with thermal energy from a solar pond as the energy source; however, the economic feasibility of this approach remains to be demonstrated.

5.3.3.4 Total Energy Systems. "Total energy" here has a very broad meaning. It could imply an energy system that supplies various types of energy, such as thermal or electrical, for various purposes or to meet varied requirements. It could also mean an energy system that can supply the same kind of energy to meet different energy needs at different times of the year, or an energy system that has the combined capabilities of the two situations just mentioned.

In agricultural applications, the energy utilization patterns for different purposes are quite different, as seen in Figure 5-15. A total solar pond energy system that will supply constant thermal energy for water heating year-round, additional thermal energy for crop drying in the fall, space heating in the winter months and cooling in the summer, electric (or shaft) power for irrigation purposes, and more heating for greenhouse operations, should be possible and much more efficient than a system with a single application. (The flow diagram for a potential system of this type is shown in Figure 4-13 and a possible application situation is shown in Figure 4-9.)

5.3.4 Potential for Solar Ponds in Agriculture

Agriculture energy uses which potentially can be supplied by solar ponds are in the areas of crop drying, livestock brooding, livestock-related and farmhouse space and water heating, greenhouse conditioning, irrigation, and possibly waste disposal. Energy consumption in these areas is tabulated (Appendix K) by fuel types and in total Btu values for each state and each solar pond application region. Table 5-25 summarizes the results for various regions and the entire nation. The table shows total agricultural energy use; total energy uses related to crop and livestock operations, respectively; and energy uses and categories which might be supplied by solar ponds. The actual replaceability, however, must be further assessed by considering the local constraints. The table does not include energy needs for farmhouse space and

Table 5-25. Solar Pond Agricultural Energy Applicability Summary (Annual Energy in 10^9 Btu)

Regions	Crops Related	Livestock Related	Total	Crop Drying	Irrigation Pumping	Livestock Brooding	Waste Disposal (Livestock)	Space and Water Heating (Livestock)	Greenhouse Conditioning	Total
Pacific Northwest	79800	7175	86975	1126	25109	274	704	496	2438	30147
Salt Lake	77613	14106	91719	2906	18738	1343	1205	704	1278	26174
Southwest	108822	12376	121198	2215	53060	975	1183	223	2945	60601
Black Hills	220118	20635	240753	13648	34981	254	669	512	3337	53401
Red River	324195	28804	353000	7725	109714	1846	1730	769	3505	124790
Great Lakes	502918	66821	569739	37654	1685	3661	7306	7133	5944	63383
Tennessee Valley	222849	40565	260414	28799	5340	8042	3345	2150	4271	51947
Gulf Coast	188780	22725	211505	10693	8662	6143	2025	929	1882	51947
Atlantic Northeast	58564	13775	72339	995	996	1709	1916	1723	12812	20151
Alaska	59	21	80	0	59	0	0	2	a	61
Hawaii	6214	297	6511	0	2465	1	36	17	a	2519
Puerto Rico	a	a	a	a	a	a	a	a	a	a
U.S.A.	1789930	224291	2014421	105261	206809	24248	20119	14658	38613	463508

[a]Information unavailable.

water heating, which can amount to an additional 3.00 x 10^{14} Btu/yr for on-farm houses only, or 1.73 x 10^{15} Btu/yr if all the rural housing units are considered (Bender, et al, 1976).

Solar pond systems that can be used to serve these energy needs can be divided into three types: single-purpose solar pond heating systems; solar pond power systems to generate electric and/or shaft power for lighting and irrigation pumping; multi-purpose solar pond total energy systems to provide varied forms of energy to serve several agricultural purposes.

However, the total energy utilization concept, serving several purposes or supplying several energy forms appears to be the most effective way to achieve broader applications on the farm.

5.4 ELECTRIC POWER SECTOR

5.4.1 Concept of Operation

One of the most attractive applications of solar ponds is in the area of electric power generation. A solar pond power plant can produce base-load or peaking electric power to match any load demand. These are options which other solar energy systems can achieve only with large investments in battery or thermal storage. However, the efficiency of the process is low and commercial electric power generation will be confined to those areas or sites where the pond ingredients occur naturally, or to sites in remote areas.

Although several processes for harvesting the thermal energy of a pond to generate electric power have been proposed, the organic Rankine heat engine is the most developed and will be used to evaluate regional solar pond power plant suitability. With this concept (Figure 5-16) the solar pond converts solar energy into thermal energy and the Rankine cycle engine transforms the thermal energy into mechanical power and turns a conventional generator. The working fluid of the closed cycle Rankine engine is typically an organic fluid like refrigerant 11 or 114, or toluene. Hot brine from the pond vaporizes the organic fluid at a modest pressure and the pond surface waters are suitable for condensing the expanded vapors. After leaving the vaporizer. the organic fluid expands across a single stage turbine wheel producing the mechanical shaft power.

The efficiencies of the process are important to the economics of the system and greatly depend upon the hot brine and cooling water temperatures. At temperatures of 175°F in the storage zone and 75°F on the surface, the efficiency of converting solar pond thermal energy to electric energy is about 8-1/2% (or approximately 64% of the Carnot theoretical maximum). The conversion efficiency, coupled with a solar pond collection efficiency of 15 to 20%, means that the total system efficiency from "solar in" to electricity out is about 1 to 1-1/2%.

The concept has been developed and proven by Ormat Turbines, Ltd. in Israel where development units of 6 kW and 150 kW are in operation; a 5-MW system is planned to start up in late 1982. In the United States a feasibility study has been completed for a large solar pond power plant in the Salton Sea in Southern California. The goals of the project are to first prove the

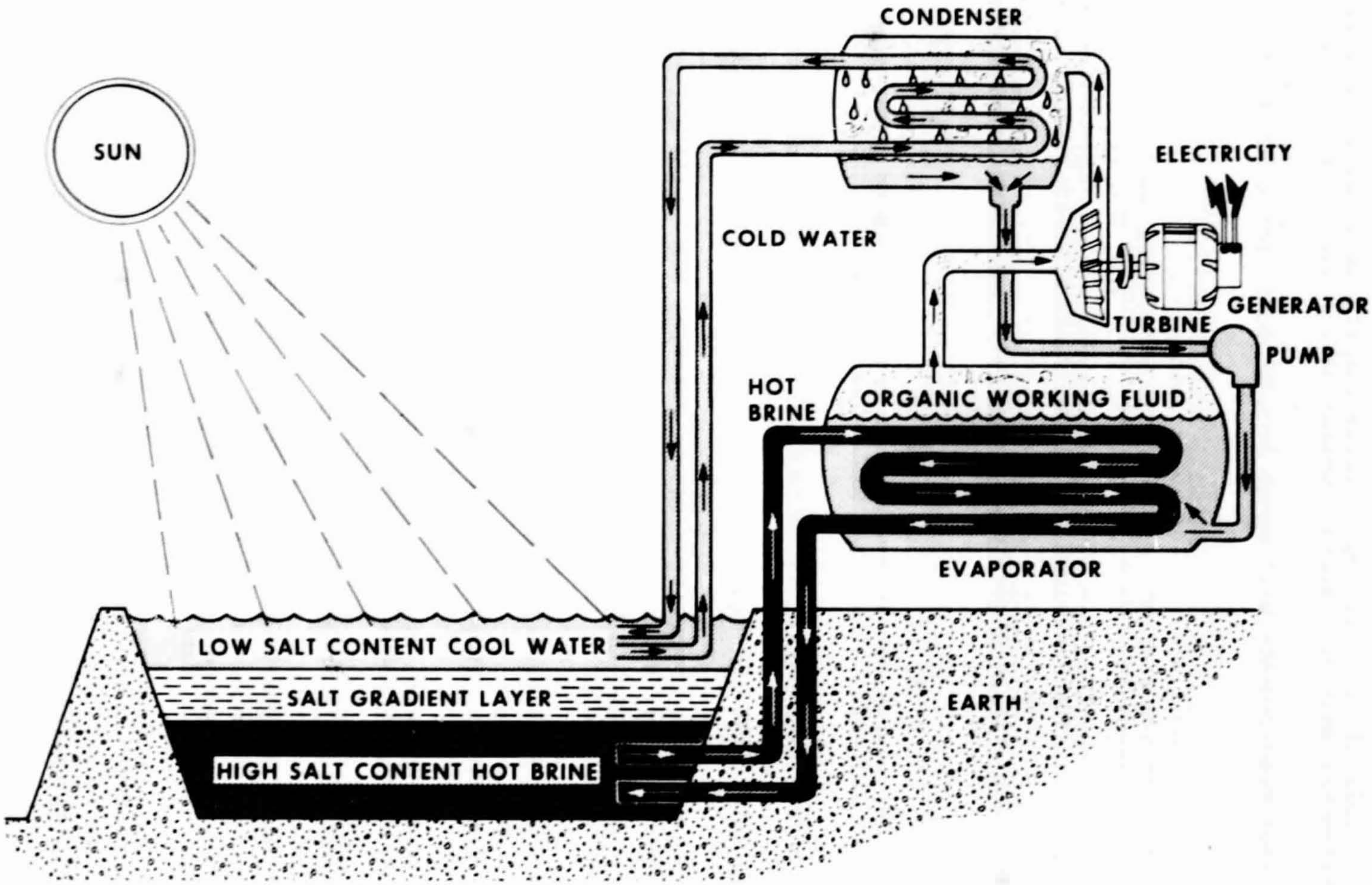


Figure 5-16. Solar Pond Power Plant Concept

concept with a 5-MW power plant experiment then to develop a commercial plant of 600 MW or more. From the work in Israel and the studies at the Salton Sea, several basic requirements for siting a solar pond power plant have emerged: high insolation, large areas of inexpensive land, readily available salt and a continuous supply of fresh or low salinity water. In areas of high insolation, a square-kilometer pond will yield a base-load net output of 2-1/2 to 3-1/2 MW. Commercial plants are envisioned to be constructed of 20- to 50-MW modules; therefore land requirements will range from 6- to 14-km^2 (1500 to 5500 acres) for each module.

An economic analysis of solar pond power plants was conducted as part of this study (Section 6). Judged from insolation and availability of other essential resources, the Southwest, Puerto Rico, Hawaii, Salt Lake, Red River and Gulf Coast were selected as the primary siting regions for solar pond power plants. The Tennessee Valley and Pacific Northwest were not included in the primary siting regions because salt reserves are not known to exist. Importing salt to these regions for solar pond power plants would likely increase busbar electric costs by more than 25%.

A clear distinction can be drawn between a solar pond that delivers thermal energy as the end product and a solar pond power plant. Because of the relatively low power conversion cycle efficiency (8 to 9%), a solar pond for electric application must be very low in cost and attain a relatively high performance. As a result, the best siting locations will be in the southern regions of the country where large areas of low-valued land, clay lining materials, abundant salt and makeup saline water are available. Importing salt or installing a synthetic pond liner will likely result in a power cost that is not competitive in the existing commercial market. Solar pond power plants will, however, be more than competitive with other solar options even if ingredients have to be imported.

There are exceptions to the general observations above. If sites can be found that have existing ponds or that have a problem of storing excess salt, technologies may be combined to yield a cost-effective power plant. The chemical industry, for example, has a large number of ponds for the storage of toxic or waste products. These might be converted into cost-effective power plants, because they will provide multiple benefits. As reported earlier, there are some 275,000 ponds in the United States, involved with industrial processes, sewage effluent, petroleum production and toxic effluent storage. Other interesting applications for power plants can be found in conjunction with chloride control projects. A river, such as the Colorado River, has tributaries which feed salt to the main body. If these tributaries are diverted into a holding area and solar ponds are constructed, salinity in the main river will be reduced, and electric power produced from an otherwise waste product.

Electric energy in remote or island locations is much more expensive than energy from the utility grid. Solar pond power plants could become the least expensive option for remote applications. In Hawaii, for example, electric energy cost is near 150 mils/kWh. However, land on islands is generally a precious entity and may offset otherwise attractive economics.

5.4.2 Potential

In the grid-connected United States, the solar pond potential appears to be resource-limited rather than need-limited. That is, the utility grid is so large that all the potential power from solar ponds could be readily absorbed by the grid. No regional considerations relative to future power needs were folded into this analysis.

In examining specific sites, difficult choices were necessary and decisions were made using a variety of criteria. For example, at the Salton Sea in California, the sea surface area is 355 mi^2. We have chosen 20% as the fraction of the sea that can be converted to solar ponds, but clearly the potential exists for more, perhaps 40 or 50%. Other evaluators could look at the same basic data and develop other choices. In this analysis, conservative assumptions were made and a large potential has resulted. Clearly, the solar pond power plant technology can be applied to more than the Salton Sea and the Great Salt Lake.

Because solar ponds have long-term storage capability and the capacity to supply high demand peaking, the installed electrical capacity for a given pond can vary widely. Capacity numbers are presented in this report in terms of average continuous net output (i.e., a load factor of one has been assumed). In addition, the numbers reported are net output. Power for parasitic losses and for pumping underground water when required have been subtracted from the gross capacity to yield net output.

The primary siting regions for solar pond electric production are those in the southern zones, Southwest, Puerto Rico, Hawaii, Salt Lake, Red River, and Gulf Coast. In the west, high insolation and a relative abundance of salt or high-saline underground water is found together with a shortage of low-saline (fresh) water. In the central or Red River region, all of the appropriate ingredients appear to be present in relative abundance. Insolation is lower than in the far west, but sufficient. Large sources of salt are readily available and water, which is in short supply on the western boundary becomes plentiful on the eastern boundary. Land and suitable clays are perceived to be relatively available. In some areas of this region, the contamination of freshwater supplies by salt and saline water excess are major problems.

The most eastern region, the Gulf Coast, has adequate insolation, a plentiful supply of water, land, and clay type soils. Salt resources are limited, except in Louisiana, and a high water table may complicate pond construction throughout the region. Ocean water could be a source of salt but the high rainfall and high relative humidity limit the use of evaporation ponds for salt production.

In the Southwest, water is the critical and limiting factor for solar ponds. Adequate data does not exist for defining the amount of available saline water and the annual replenishment. Most water studies have been directed toward freshwater supplies. A solar pond will require as much as 16 acre-ft of water per acre of pond for the initial fill and from a 7 to 9 acre-ft per year of evaporation replenishment water. The annual replacement is truly the factor that limits the potential in the Southwest. If effective means of controlling evaporation could be found, the solar pond potential

would be greatly expanded. For this evaluation no consumption of fresh water in water-short areas has been assumed.

An alternative to using local water is importing ocean water. In Southern California, coastal property is highly valued, and flat open areas near the ocean are not candidate sites. However, it is conceivable to bring ocean water into the lower California desert or into Arizona from the Gulf of California, a distance of 40 mi. Water costing $100/acre-ft will translate to an increase of about $0.01/kWh in busbar electric cost. However, this concept is beyond the scope of this study.

Along the Texas Gulf Coast, ocean water for solar pond surface washing appears very plausible. In island installations, using ocean water is a basic prerequisite. As average humidity increases, evaporation losses and the ability to make brine from ocean water diminish. This has positive and negative effects and emphasizes the fact that solar ponds will be site specific not only in terms of construction but also in terms of operation and maintenance.

The discussion that follows supports the summary of solar pond power-plant potential presented in Table 5-26. Each state in the primary siting regions is discussed. A list of specific potential solar pond sites for electric power generation is presented in Table 5-27.

5.4.2.1 Southwest Region.

5.4.2.1.1 California. The largest potential site in California is clearly the Salton Sea. The Salton Sea is 355 mi^2 and if 20% of the sea is converted into solar pond power plants, a net power output of 650 MW can be realized. Other water bodies include San Francisco Bay and San Diego Bay. San Diego Bay does not appear large enough to support a commercial power plant. Many smaller potential sites exist within the state and have the necessary ingredients of high insolation, land area and salt, but are limited by water for evaporation make up.

These sites are typically inland dry desert lakes with surface salt crusts and underground saline water. Water and brine for initial pond fill are frequently available but the long term evaporation make up source is unknown.

One approach in estimating potential make up water is looking at the reported average water depth at inland nominally dry lakes following a winter season. Normally such water is contained at the surface by impervious clays until evaporation causes it to disappear. If a portion of this water could be channeled into storage, perhaps underground, then a reliable source of replenishment water might be created. Such a scheme might involve pumping down the existing saline water table and building percolation basins to quickly dispose of surface water. In Table 5-26, a notation indicating surface water management reflects managing winter rainwater accumulation and preserving a portion (50%) for supplying water to the surface of solar ponds.

Along the border between California and Mexico and near the Pacific Ocean, there is an area in which ocean water could be imported to

Table 5-26. Solar Ponds: Electric Power Potential

State	Baseload Average MWe (Net)
California	2,000[a]
Nevada	380[a]
Utah	5,000
Arizona	360[a]
Colorado	360
New Mexico	700[a]
Oklahoma	2,300
Texas	20,000
Louisiana	4,000
Mississippi	500
Georgia	400
Florida	2,000
Total	38,000 MWe ~ 3.4 quads

[a]In "dry" desert lake locations, a water management scheme has been assumed to collect and store surface water runoff from winter rains.

create a large solar pond. An estimate of this potential as well as other inland sites is presented in Table 5-26. The potential for California is judged to be 2000 MW.

5.4.2.1.2 Arizona. The limiting factor in Arizona is water. As part of the Colorado River Chloride Control Project, sufficient Colorado river water would be diverted in Arizona to support 360 MW of solar pond electric production. Sites around Phoenix have also been suggested. Salt is readily available and saline water sources have been identified but the extent of the resource cannot not be determined. Therefore no assessment of the Phoenix potential is included.

5.4.2.1.3 Nevada. There are three candidate sites in Nevada: Walker Lake, Carson Sink, and an additional element of the Colorado River Chloride Control Project. Walker Lake is similar to the Salton Sea in that it is becoming more

Table 5-27. Specific Potential Solar Pond Sites for Electric Power Generation

State	Potential Solar Pond Site
Alabama	McIntosh Dome, Klepac Dome, Mobil Bay-Alabama River
Arizona	Phoenix, Yuma, Supai Basin, Red Lake, Haulpai Valley, Detrital Valley
California	Salton Sea, Owens Valley, Castac Lake, Bristol Lake, Searles Lake, Dale Lake, Danby Lake, Soda Lake, West Great Central Valley, Koehn Lake, Honey Lake, Mono Lake, San Francisco Bay
Colorado	Permian Basin, Paradox Basin
Florida	Coastal Areas
Louisiana	Salt Domes, Coastal Zones
Mississippi	Salt Domes, Coastal Zones
Nevada	Virgin Valley, Carson Sink, Esmeralda County, Diamond Valley, White Plains, Dixie Salt Marsh
New Mexico	Permian Basin, Tularosa Basin, Carlsbad-Pecos River
Oklahoma	Permian Basin, Great Salt Plain, Big Salt Plain
Texas	Permian Basin, Gulf Coast Basin, Galveston Bay
Utah	Great Salt Lake, Sevier Lake, Paradox Basin, Bonneville Salt Flats

saline. The concept proposed for the Salton Sea, of diking a portion of the lake to achieve lake salinity control, could be applied to Walker Lake. Diking 20% of Walker Lake and creating solar pond power plants could produce 120 MW of electric power.

Carson Sink is 450 miles in area, and receives water from the Carson and Humbolt Rivers. Salt is readily available and the area is underlined with clay and saline water. An estimate of 260 MW has been made for Carson Sink.

The third Nevada site utilizes Colorado River water, is part of the Colorado River Chloride Control Project, and was taken from the Bureau of Reclamation's Colorado River Study.

5.4.2.1.4 New Mexico. The most interesting potential in New Mexico is in the Pecos River area or southeast plains. Large quantities of salt are being introduced into the Pecos River creating a severe contamination problem. The information from New Mexico indicates that water should be available to support approximately 36 mi^2 of solar ponds. In addition, if underground brine is pumped, an estimated potential of 700 MW results. Near Carlsbad and Rosewald, New Mexico, there is a potash industry. Although natural ponds exist and excess brines are available, there is not sufficient data to assess a potential for developing solar ponds. One of the needs of this area may well be a desalination plant.

5.4.2.2 Salt Lake Region.

5.4.2.2.1 Utah. The summary solar pond potential in Utah is the Great Salt Lake. This large, highly concentrated saline body of water has been clearly recognized as a major site for solar pond development. This was recognized early in the Regional Assessment study and a specific Utah assessment was commissioned to Drs. Paul Riley and Clair Batty of Utah State University (1981).

A master plan for the Great Salt Lake has been proposed and developed by Drs. Riley and Batty which recognizes the industrial, social and recreational needs of the area. The lake is subdivided and developed into solar ponds, high concentrated regions for supporting mineral extraction industries, low salinity areas and a freshwater zone for recreation (Figure 5-17). This plan proposes lake management which will develop the resource in an environmentally acceptable manner. The total Great Salt Lake potential is 4000 MW.

Utah has other vast resources of open land and salt. However, water becomes a limiting factor away from the Great Salt Lake. Integrating solar ponds with oil shale development is a concept needing additional evaluation, as a by-product of the oil-shale operation would be large quantities of brine or contaminated water. Also, oil-shale operation would require substantial electric power. A preliminary estimate of this potential in Utah has been provided as 0.15 quads/yr (Riley and Batty, 1981).

The overall total Utah solar pond power production has been estimated to be 5000 MW.

5.4.2.2.2 Colorado. Colorado has excess salt brine and salt-rich shale in Paradox Valley. Two hundred thousand tons of salt are estimated to enter the Dolores River annually. Control concepts involve pumping of the brine waters into evaporation ponds as an alternative to letting the brine flow into the Dolores River. Again, the availability of make up water becomes a limiting factor. From the Bureau of Reclamation Study of Colorado River Chloride Control, there appears to be a potential for developing 360 MW of solar pond power.

Like Utah, Colorado has vast reserves of oil shale. In the northwest corner of Colorado a synfuel production operation which would require large quantities of electric power could be undertaken to produce large quantities of brine and contaminated water. A detailed study of this

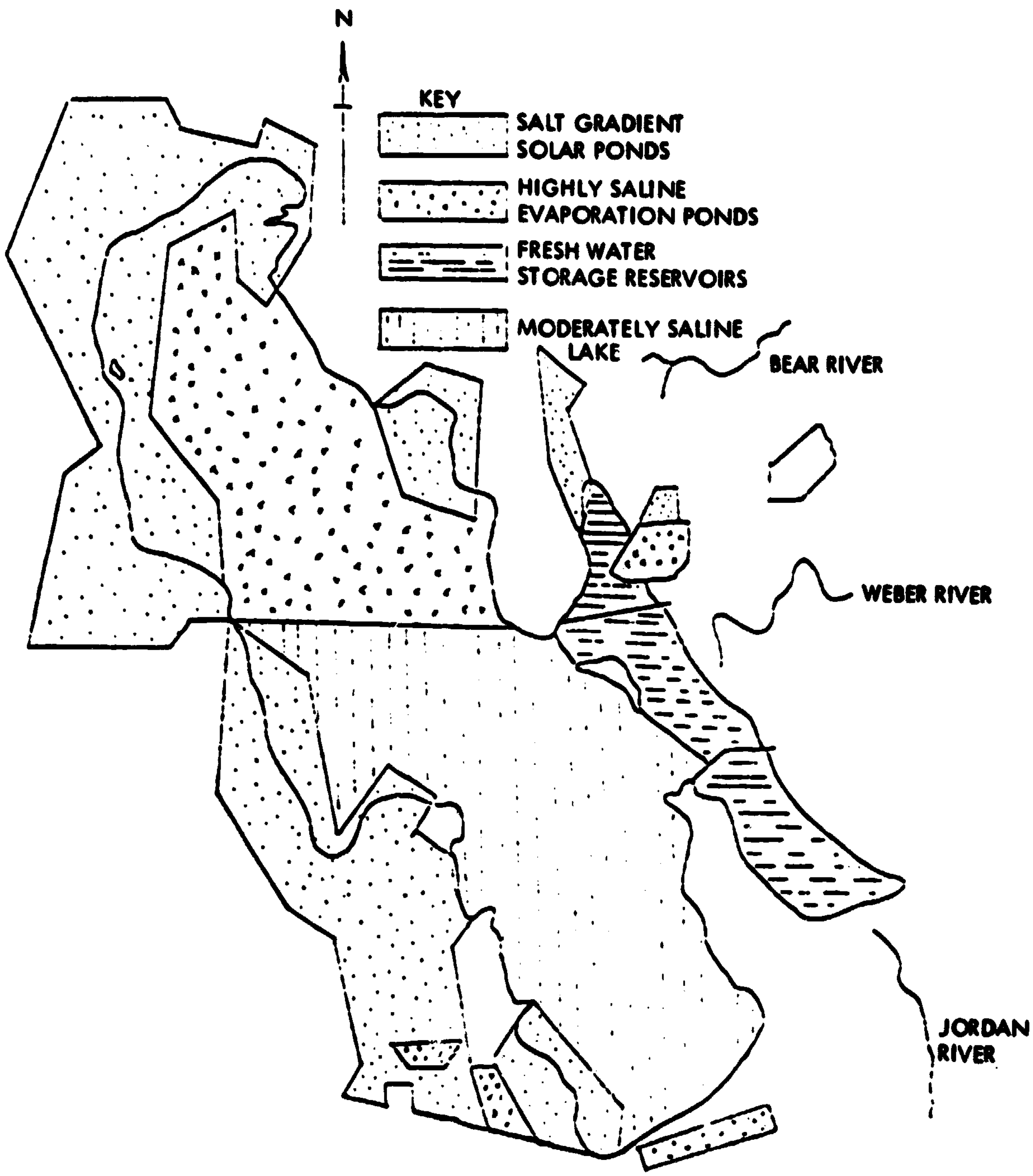


Figure 5-17. Elements of Possible Scenario for Developing the Energy Potential of the Great Salt Lake

concept should be undertaken and the integration of solar ponds into the oil-shale operation evaluated. No potential is included in this assessment.

5.4.2.3 Red River Region.

5.4.2.3.1 Oklahoma. Water is more available in Oklahoma than in the far west and evaporation rates are lower. For this assessment, Oklahoma is divided into east and west portions. In the west, the focus is the Cimarron River area where 2,600 tons of salt per day are reported to be carried away and evaporation ponds exist for the production of commercial salt. Apparently, underground water is available in addition to surface water for the production of about 1400 MW of power. In east Oklahoma, the focus is principally on the Red River and the Arkansas River, which contain high levels of salt. Intercepting the saline water in-flows and diverting them to enclosed areas is a feasible concept and compatible with the creation of solar ponds. This area is being studied in detail by the Army Corps of Engineers, Tulsa District. In attempting to estimate the pond potential two approaches can be taken: (1) use only the diverted saline water, or (2) supplement the saline waters with other available ground and river waters. If only diverted saline waters are used, the power potential has been estimated at 400 MW. Using supplementary water might increase this potential to 900 MW.

5.4.2.3.2 Texas. Texas may be the most ideal state for solar pond power plants. Approximately half the state is said to be underlaid with salt and saline water. The Permian Basin in the western panhandle has a salt resource that is measured in cubic miles. Another huge salt resource is located in east Texas. The major salt beds are the Haynesville Salt and Louann Salt which contain bedded salt, salt domes and brines.

The extent of water availability in west Texas is uncertain but saline ground water is reported over most of the area. Water sources in the west include the Pecos, Red, Colorado, and Canadian Rivers plus irrigation runoff. In assessing the potential, an assumption was made that ponds could be constructed almost anywhere, i.e., that surface characteristics are very uniform. If 0.5% of the land area were converted to solar ponds then 2000 MW of power could be produced in the Permian Basin alone.

The southern tip of Texas is characterized by an arid landscape, a humid climate and extensive underground saline water and salt deposits. The Rio Grande River is also a potential source of water. In addition, the area is sufficiently close to the ocean to think in terms of utilizing ocean water. If 5% of Texas' 80,000 km^2 could be converted to solar ponds, a potential of 8000 MW would result.

East and central Texas also have ample surface water and are near the ocean. Along the coastline, the Barrier Islands enclose bays. On land, private and state ownership of large tracts exist. The amount of land and coastline that could be dedicated to solar ponds is a question that must be answered by the Texas resident. However, a 5% land area dedication would yield 10,000 MW of electric power potential.

5.4.2.4 Gulf Coast Region.

5.4.2.4.1 Louisiana. Louisiana has large amounts of saline water. Throughout the state are deep sources of saline water and in some places exist salt domes. State officials imply that land is probably available, although the water table is generally very high. Large quantities of grey to red clay exist throughout the area. Louisiana, like Texas, appears to have the necessary ingredients for solar ponds providing one finds the right specific contour at any site. If 2% of the land area could be converted to solar ponds, then the potential in Louisiana is estimated to be 4,000 MW.

5.4.2.4.2 Mississippi. The southern portion of Mississippi has salt and a small potential for solar ponds, perhaps 500 MW.

5.4.2.4.3 Alabama. Alabama, much like Mississippi, seems to have a small potential for solar pond power plants in the southern regions.

5.4.2.4.4 Georgia. There are no known salt sources in Georgia. Again, we have the characteristic of high ground water, high humidity, and no readily available salt. Georgia, however, has extensive amounts of clay and swamp areas that potentially could be converted to solar ponds. Assuming that ocean water is used as a salt source, the estimate for Georgia is 400 MW.

5.4.2.4.5 Florida. Florida can be viewed in terms of the panhandle area and the peninsula area. Characteristics of Florida are a high water table and a lack of salt. However, the potential might be very large if (1) ocean water is imported and brine made from ocean water, or (2) if the importation of salt via ocean shipping can be realized. In the panhandle area the estimated potential is 500 MW.

Institutions in Florida are interested in the solar pond concept and are studying pits remaining from the mining of phosphate ore. Large land areas are being exposed in this manner which are otherwise unusable because of low-level residual radiation. One of the concepts being promoted for Florida is combining solar ponds, open phosphate pits, and new generation coal-fired power plants. The coal-fired power plants will utilize calcium-carbonate in cleaning the flue gas. This will generate large quantities of calcium-sulfate mixed with fly ash. This material is likened to a low-grade cement. If handled quickly, it can be spread on the bottom of the phosphate ponds to any depth desired, creating an impervious liner. An enormous quantity of residue phosphate fly ash is expected to be generated which will be sufficient for lining many solar ponds. Therefore, the estimated potential for Florida is 2000 MW.

5.5 DESALINATION SECTOR

5.5.1 Desalination Processes

The separation of water from salts in an aqueous solution can be accomplished by a number of desalination processes. A complete listing of the

available processes is presented in Table 5-28. For a thorough discussion of these processes, the reader is referred to the literature (e.g., Catalytic, Inc., 1979). The present discussion of solar pond applicability to and potential for desalination applications is limited to those processes that are approaching technological maturity and appear to be promising in terms of wide-scale usage. These processes are distillation (either multistage flash or vertical-tube evaporators) and reverse osmosis for high salinity feed waters, and reverse osmosis and electrodialysis for low salinity feedwaters (Larson and Associates, 1977).

A substantial desalination market is expected in the United States by the year 2000. As of May 1981, the total installed plant capacity was 272.9 million gal/day (mgd), up from 100.3 mgd in 1977 (El-Ramly and Congdon) 1977; El-Ramly and Congdon, 1980). The demand is expected to continue growing largely due to the impact of the Federal Water Pollution Control Act, the Safe Drinking Water Act, and also in response to local water shortages. Arthur D. Little, Inc., in a 1972 report sponsored by the U.S. Department of Interior (Office of Saline Water), projected the size and regional distribution of the U.S. desalination market (Rothmerel, 1972). Of the demand projected for the year 2000, desalination of high-salinity feedwater (ca. 35,000 ppm, as for sea water) and of low-salinity feedwater (ca. 2,000 to 5,000 ppm, as for brackish or waste waters) would amount to 2003 mgd and 516 mgd, respectively. The Fluor Co., in a 1978 report to the U.S. Department of the Interior (Office of Water Resources Technology) projected a demand of 970 mgd and 18,090 mgd for high- and low-salinity feedwaters, respectively (Flour Engineers and Constructors, Inc., 1978). A major source of the above discrepancy results from differing projections of the market size for cleanup of return flows from manufacturing and thermal electric generation (Table 5-29).

The projections of solar pond potential for desalination presented herein are based on the lower desalination market projections given in the 1972 Arthur D. Little report. This is an arbitrary choice but reflects the rough correlation of the 1972 estimate for 1980 total desalting demand (301 mgd) with the actual 1981 total installed desalting plant capacity (273 mgd). In addition, the 1972 report includes estimates of the regional distribution of the desalination market. These estimates are useful in projecting the regional distribution of the potential market for solar ponds in desalination.

The following sections describe the applicability and regional potential of solar ponds as an energy source for the various desalination technologies.

5.5.2 Desalination Technologies and Their Energy Requirements

Desalination processes are based on a change of phase (distillation and freezing), on selective transport using membranes (electrodialysis and reverse osmosis), or on chemical bonding (ion exchange). A general schematic of plant components common to all desalting processes is shown in Figure 5-18. The feedwater is screened to remove suspended solids and debris and then treated to prepare the water for desalination and to ensure more efficient and troublefree plant operation. The primary plant effluents are product water and concentrated brine reject streams. In some processes, a vent stream is required to remove gaseous byproducts. The nature of the post-treatment step

Table 5-28. Desalination Process Categorization

Category	Process
Phase Change: Distillation	Vertical Tube Evaporator
	Multistage Flash
	Vapor Compression
	Single-effect Solar Still
	Multi-effect Solar Still
Phase Change: Crystallization	Vacuum Freezing/Vapor Compression
	Secondary Refrigerant Freezing
	Hydrate Formation
Membrane	Electrodialysis
	Transport Depletion
	Reverse Osmosis
Chemical	Ion exchange
Combinations of the Above	

Table 5-29. Desalting Market Projections for the Year 2000

	Projections	
Feedwater Type	Arthur D. Little	Fluor Engrs.
Low-Salinity	516.4 mgd	28,090 mgd
High-Salinity	2002.8 mgd	910 mgd
Total	2519.2 mgd	29,000 mgd

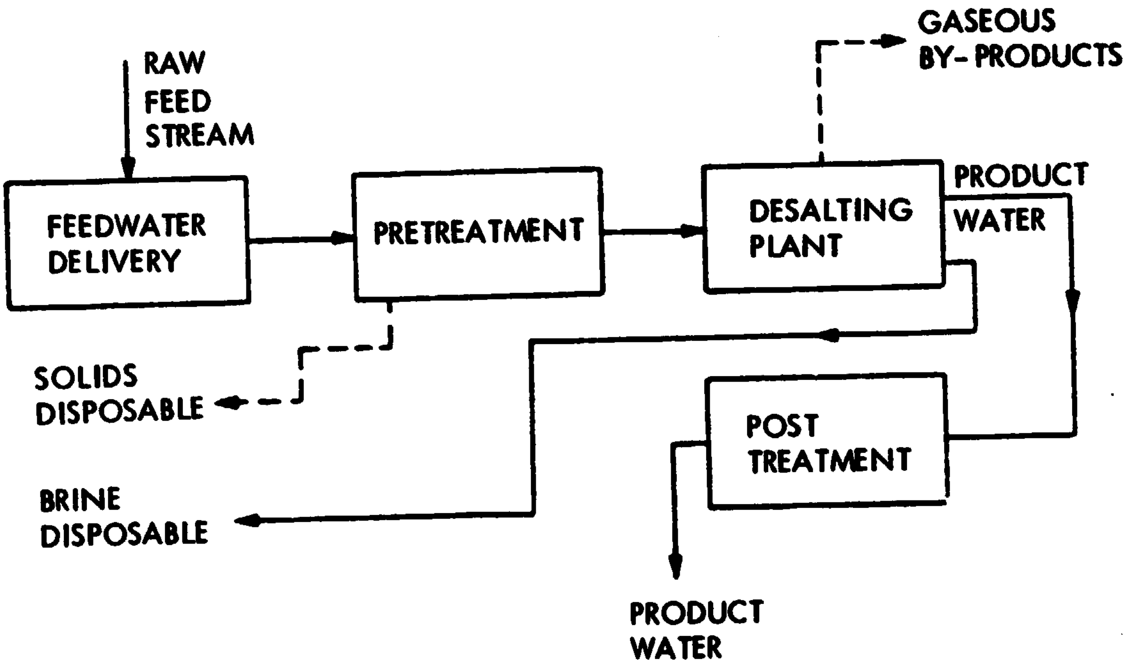


Figure 5-18. General Desalting Plant Schematic (Source: Catalytic Inc., 1979)

depends on the intended water use. The processes most likely to be commercialized on a large scale are discussed briefly below.

The distillation process is based on the evaporation of water from a saline solution (Figures 5-19 through 5-22). The dissolved solids, being less volatile than water, remain in solution. There are several variations of the distillation process including multistage flash evaporation, multiple-effect evaporation (in particular, vertical tube evaporation), and vapor compression. The energy input to the process is the thermal energy required to vaporize the water in the saline solution and mechanical energy to pump the process streams through the plant. The mechanical energy is typically derived directly from electrical energy.

In reverse osmosis, dissolved solids are separated from water by imposing a relatively high pressure (ca. 400-600 psi) on a saline solution in contact with a semi-permeable membrane (Figures 5-23 and 5-24). As the pressure is applied, relatively pure water is transported through the membrane leaving a more concentrated solution (brine waste) on the high pressure side. The energy input to the process is purely mechanical (electrical) to drive the pumps.

The electrodialysis process removes dissolved solids by applying an electric potential across a set of alternately stacked anion-permeable and cation-permeable membranes (Figures 5-25 and 5-26). Thus, dissolved ions move through the membranes to produce alternate channels of relatively pure water and more concentrated brine. The energy input to the process is the mechanical (electrical) energy required for pumping and the electrical energy required to establish the driving potential for ion migration.

Product water costs for distillation do not increase significantly as feedwater salinity increases, whereas the opposite is true for the membrane processes. Therefore, although membrane processes are economically attractive for desalination of low-salinity feedwater, distillation remains competitive for high-salinity feedwater.

The thermal and electrical energy requirements for multi-stage flash evaporation at a relatively high temperature (266°F) and at a lower value (194°F), for electrodialysis of several feedwaters of varying composition, and for vertical tube evaporation and reverse osmosis are shown in Table 5-30. Capital, operating and maintenance, conventional energy costs, and final water costs are shown in Tables 5-31 through 5-34. The variance of electrodialysis energy requirements and costs with composition for low-salinity feedwater is shown for different low-salinity feedwaters representative of the range of waters found throughout the United States (Table 5-35).

5.5.3 Solar Pond and Desalination Plant Process Coupling

It is possible to use a solar pond to supply thermal, mechanical or electrical energy to a desalination process. The possible energy path coupling configurations of a solar pond, a secondary energy source and a desalination plant are shown in Figure 5-27. It is also possible to use the waste brine effluent from the desalination plant as a feed stream to evaporation ponds for production of concentrated brine for maintenance of the solar pond or for initial filling of additional solar ponds at the nearby

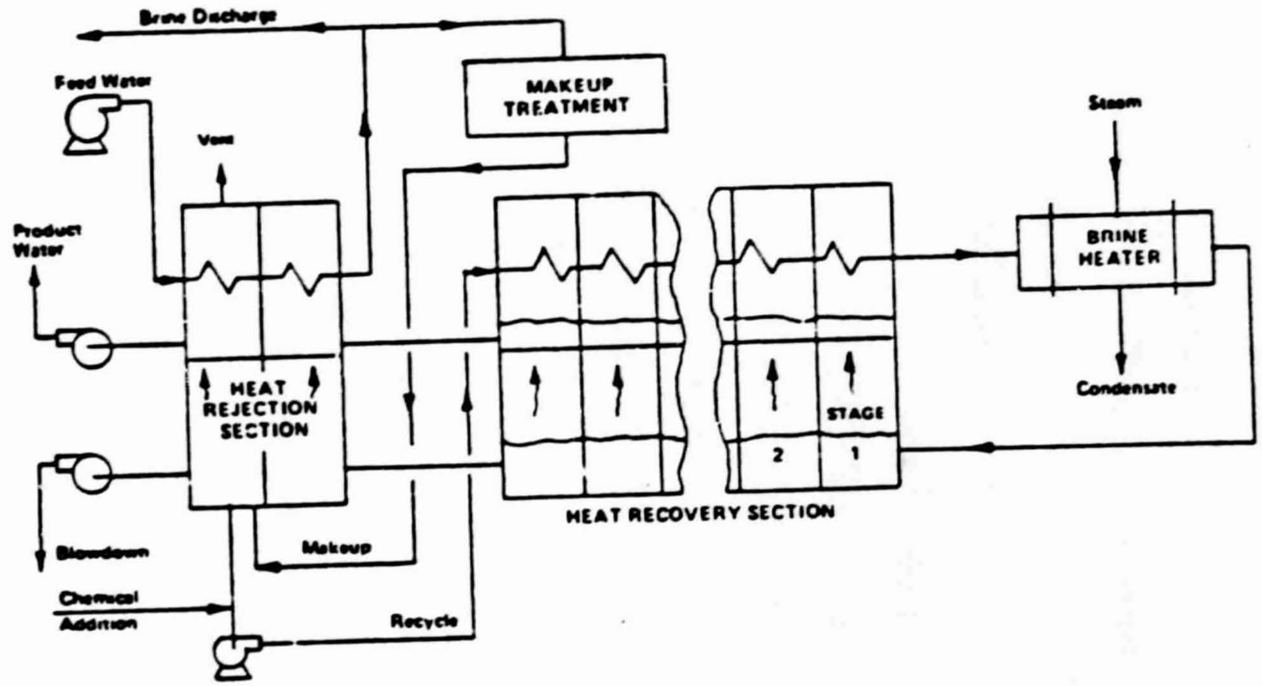


Figure 5-19. Multistage Flash Evaporator Plant Schematic (Source: Catalytic, Inc., 1979)

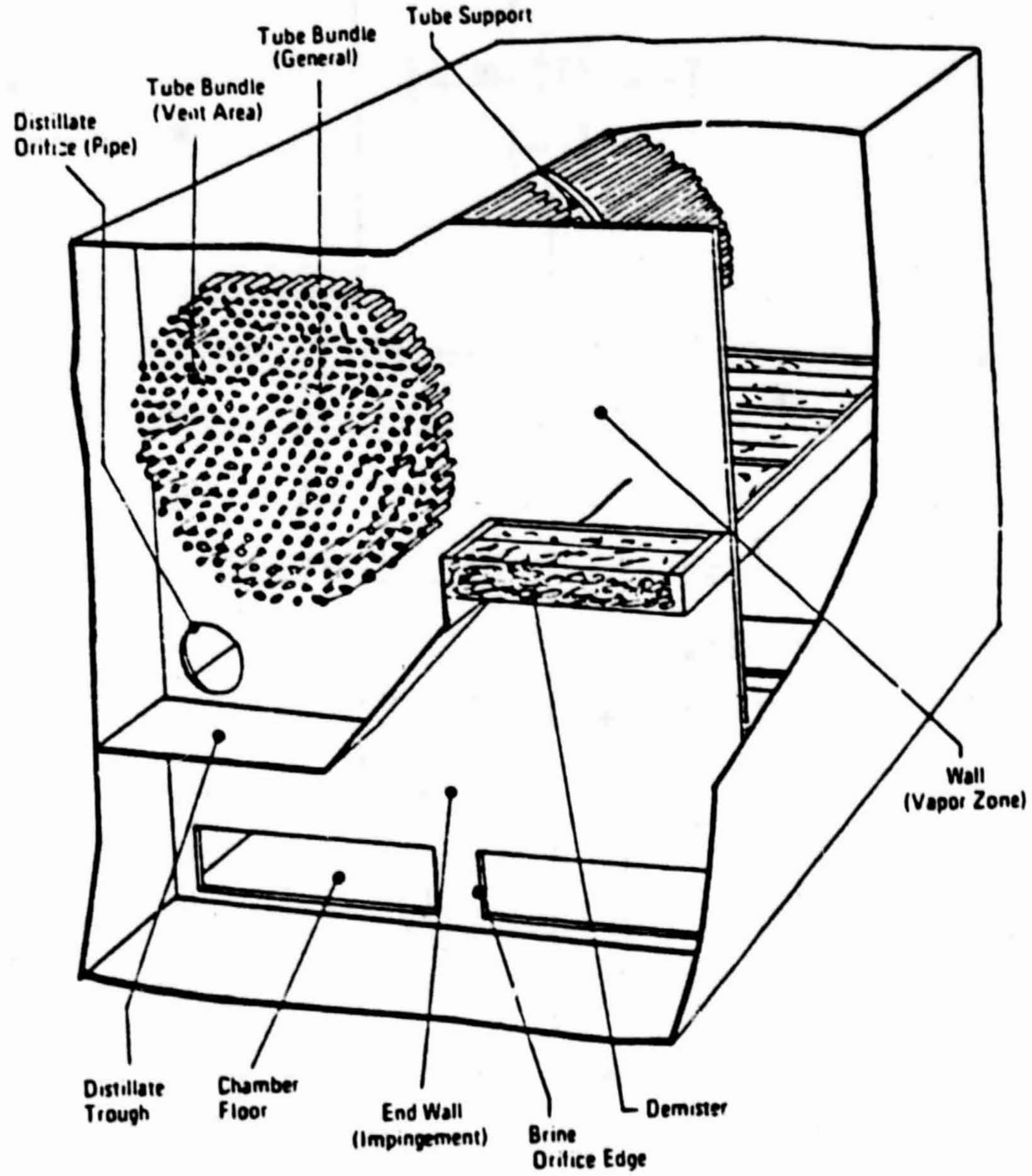


Figure 5-20. Cut-Away Flash Evaporator Stage (Source: Catalytic, Inc., 1979)

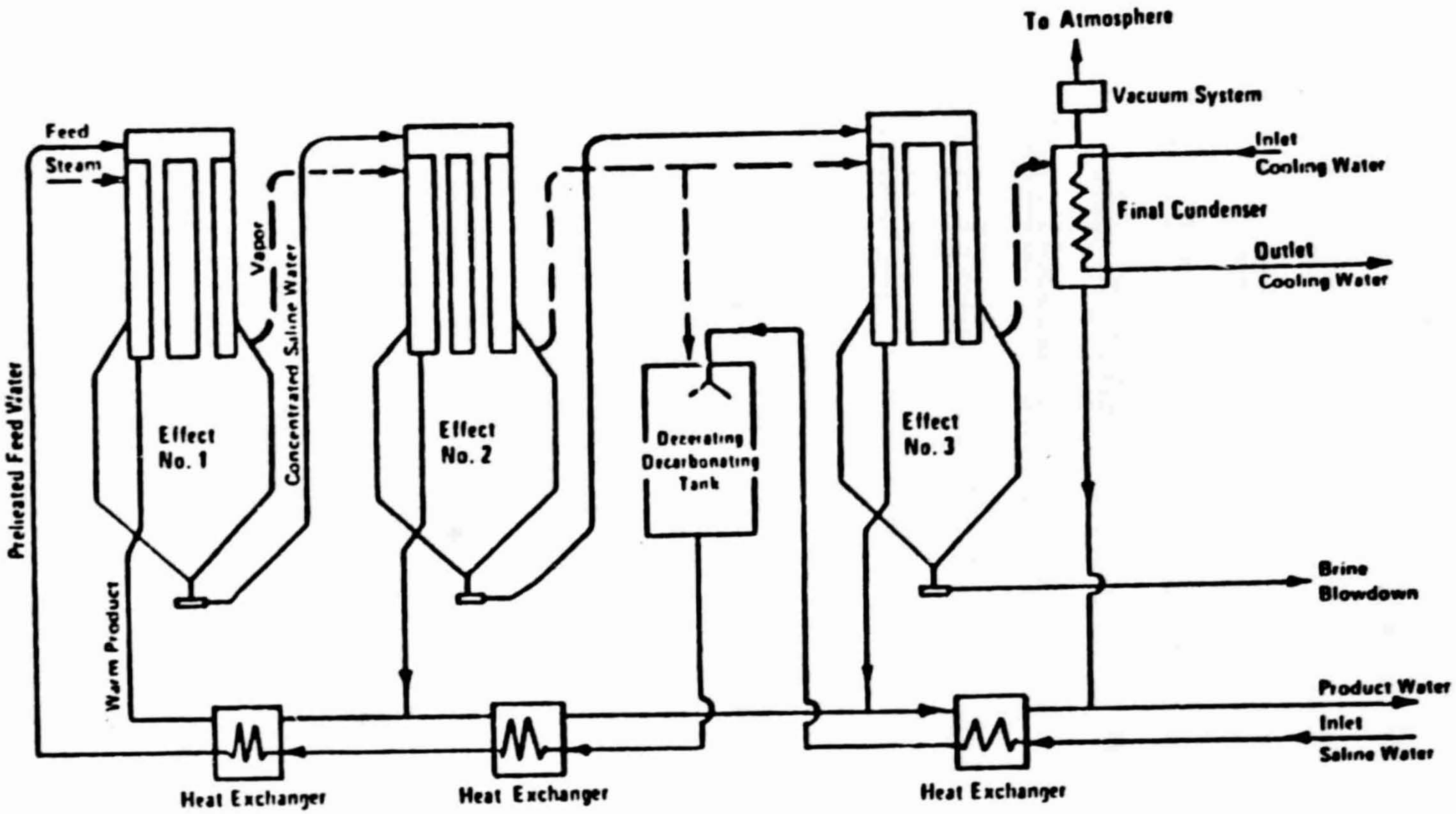


Figure 5-21. Triple-Effect Falling-Film (VTE) Desalting Process
(Source: Catalytic, Inc., 1979)

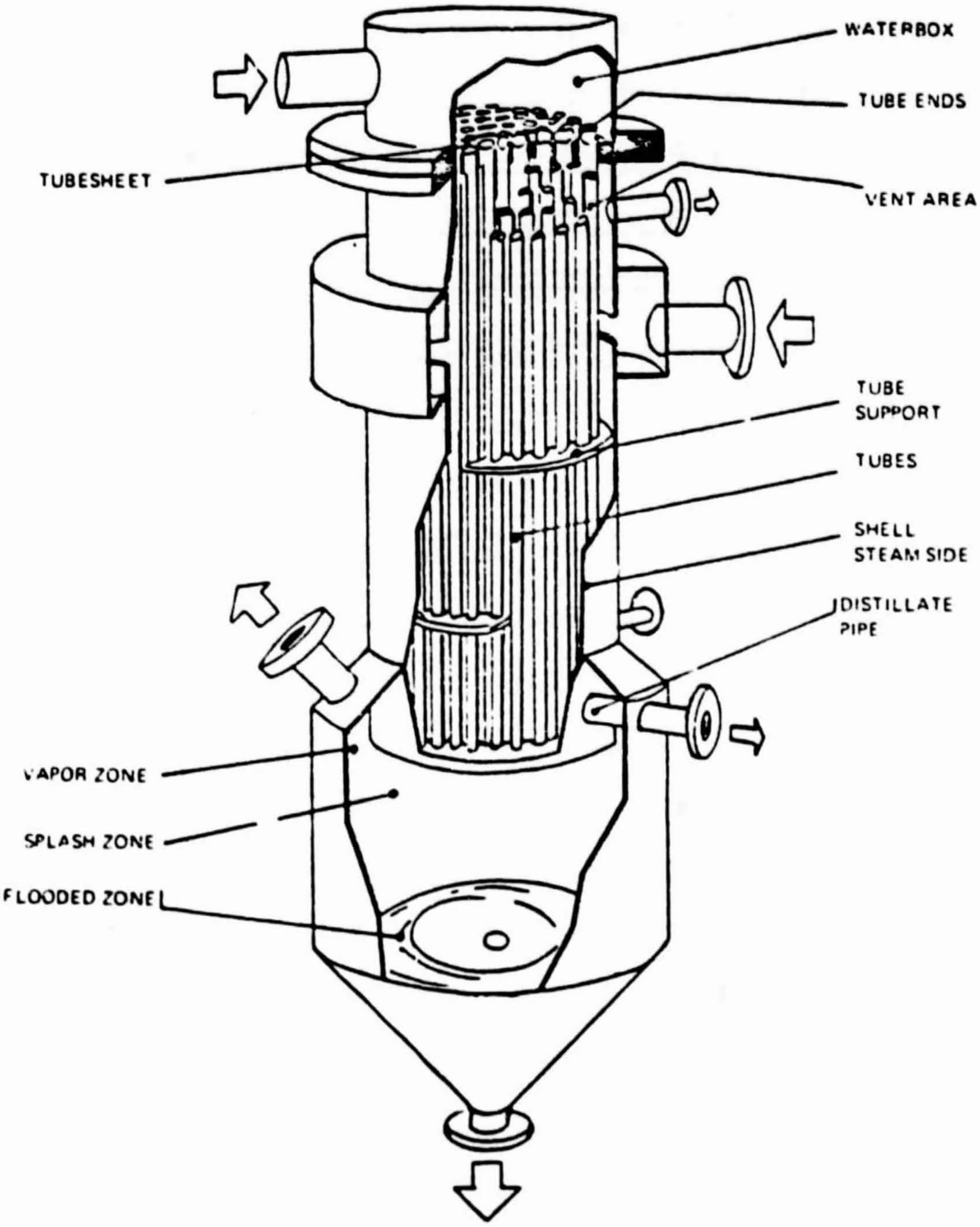


Figure 5-22. Cut-Away Vertical Tube Evaporator (Source: Catalytic, Inc., 1979)

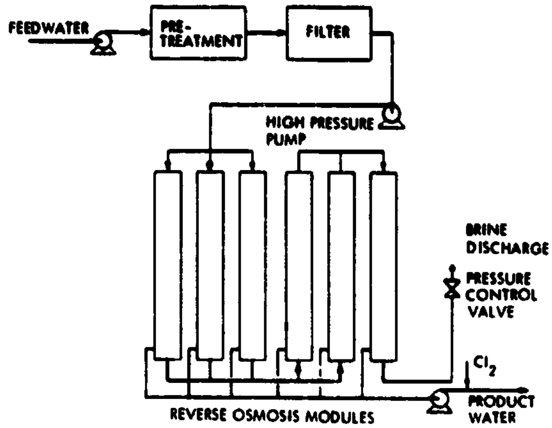


Figure 5-23. Reverse Osmosis Plan Flowchart (Source: Catalytic, Inc., 1979)

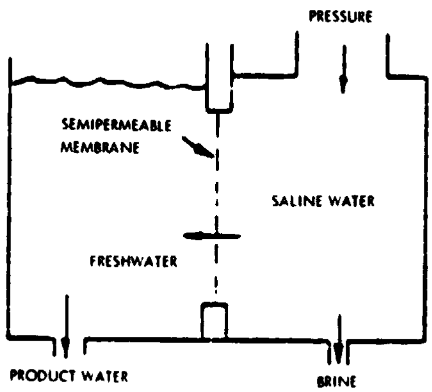


Figure 5-24. Principle of Reverse Osmosis (Source: Catalytic, Inc., 1979)

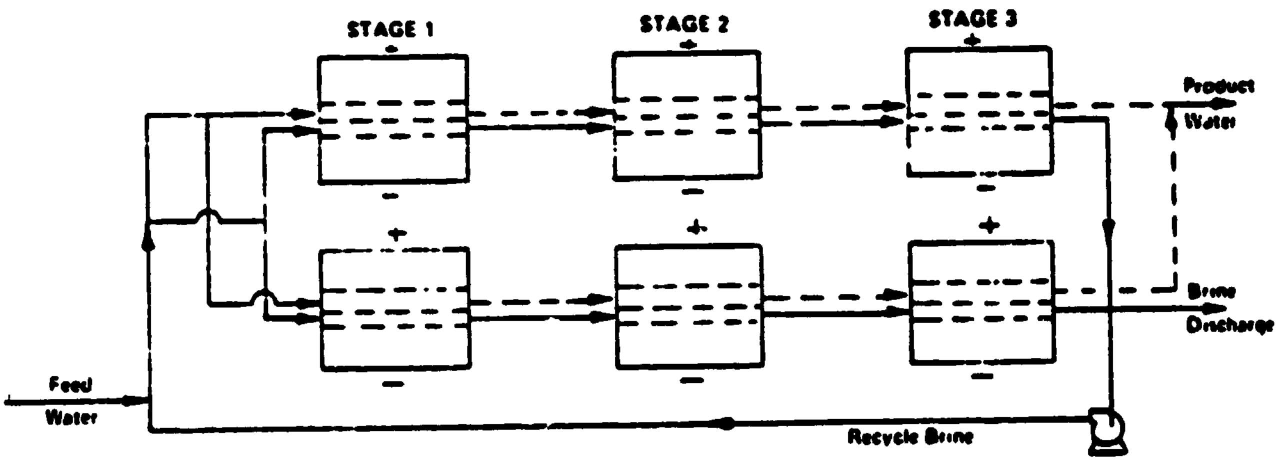


Figure 5-25. Electrodialysis Flowchart (Source: [illegible], Inc., 1979)

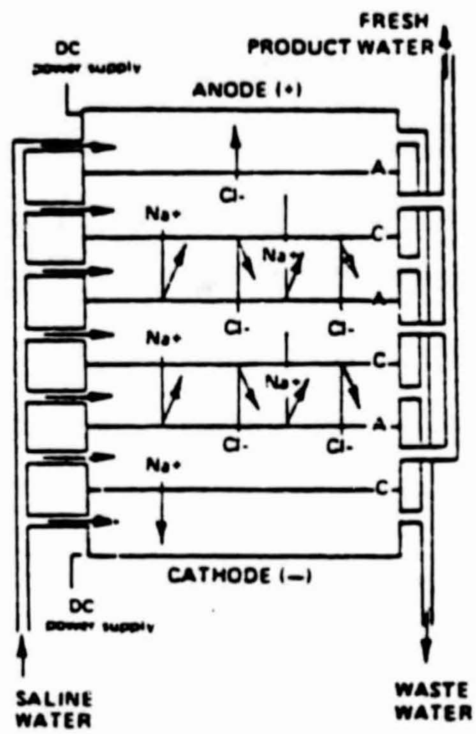


Figure 5-26. Electrodialysis Stack Schematic (Source: Catalytic, Inc., 1979)

Table 5-30. Desalination Thermal and Electrical Energy Requirements[a] (in SI and conventional units)

Feedwater:	Low Salinity (2,000-5,000 ppm)				High Salinity (35,000 ppm)			
	Electrical		Thermal		Electrical			Thermal
	MJe/m^3	(kWhe/kgal)	MJt/m^3	(lb/kBtut)	MJe/m^3	(kWhe/kgal)	MJt/m^3	lb/kBtut[b]
Process:								
Distillation								
MSF(129°C)[c]	-----	-----	-----	-----	4.8	(5.0)	194	(12)
VTE(129°C)[d]	-----	-----	-----	-----	2.4	(1.5)	194	(12)
MSF(90°C)	-----	-----	-----	-----	10.3	(10.8)	232	(10)
Reverse Osmosis	9.5	(10.0)	-----	-----	36.1	(38.0)	-----	-----
Electrodialysis								
Water Type[e] #1	10.4	(11.0)	-----	-----	-----	-----	-----	-----
#2	5.9	(6.2)	-----	-----	-----	-----	-----	-----
#3	7.1	(7.5)	-----	-----	-----	-----	-----	-----
#4	13.1	(13.8)	-----	-----	-----	-----	-----	-----

[a]Source: Larson and Associates, 1979.

[b]"lb/kBtut" is the so-called "performance ratio" and "kWhe/kgal" is a convenient measure of electrical energy usage.

[c]Multistage flash distillation.

[d]Vertical tube evaporator distillation.

[e]Compositions of water types #1 through #4 are given in Table 5-35.

Table 5-31. Fixed Charges for Desalted Water: First Quarter, 1979[a] (costs in \$/kgal)

Feedwater	Low Salinity (2,000-5,000 ppm)			High Salinity (35,000 ppm)		
Process						
Plant Capacity (mgd)[b]	----------	----------	----------	1.0	5.0	100.0
Distillation						
MSF(129°C)[c]	----------	----------	----------	4.66	3.21	1.74
VTE(129°C)[d]	----------	----------	----------	4.18	2.87	1.31
MSF(90°C)[c]	----------	----------	----------	4.86	3.94	f
Plant Capacity (mgd)	1.0	5.0	25.0	1.0	5.0	
Reverse Osmosis	0.70	0.47	0.40	2.60	2.36	
Plant Capacity (mgd)	1.0	5.0	25.0	----------	----------	----------
Electrodialysis						
Water Type[e] #1	0.80	0.71	0.59	----------	----------	----------
#2	0.71	0.61	0.50	----------	----------	----------
#3	0.60	0.51	0.41	----------	----------	----------
#4	0.73	0.63	0.51	----------	----------	----------

[a]Source: Larson and Associates, 1979.

[b]mgd = million gallons per day.

[c]Multistage flash distillation.

[d]Vertical tube evaporator distillation.

[e]Compositions of water types #1 through 4 are given in Table 5-35.

[f]Information unavailable.

Table 5-32. Operating and Maintenance[a] Charges for Desalted Water: First Quarter, 1979[b] (costs in $/kgal)

Feedwater	Low Salinity (2,000-5,000 ppm)			High Salinity (35,000 ppm)		
Process						
Plant Capacity (mgd)[c]	—	—	—	1.0	5.0	100.0
Distillation						
MSF(129°C)[d]	—	—	—	0.90	0.37	0.26
VTE(129°C)[e]	—	—	—	0.86	0.32	0.22
MSF(90°C)[d]	—	—	—	0.92	0.40	g
Plant Capacity (mgd)	1.0	5.0	25.0	1.0	5.0	
Reverse Osmosis	0.42	0.35	0.30	1.06	2.00	
Plant Capacity (mgd)	1.0	5.0	25.0	—	—	—
Electrodialysis						
Water Type[f] #1	0.25	0.19	0.14	—	—	—
#2	0.24	0.18	0.13	—	—	—
#3	0.22	0.16	0.11	—	—	—
#4	0.23	0.18	0.13	—	—	—

[a]Includes general and administrative costs, supplies and maintenance, chemicals and materials.

[b]Source: Larson and Associates, 1979.

[c]mgd = million gallons per day.

[d]Multistage flash distillation.

[e]Vertical tube evaporator distillation.

[f]Compositions of water types #1 through 4 are given in Table 5-35.

[g]Information unavailable.

Table 5-33. Conventional Energy Charges for Desalted Water: First Quarter, 1979[a] (costs in $/kgal)

Feedwater	Low Salinity (2,000-5,000 ppm)	High Salinity (35,000 ppm)
Process		
Distillation		
MSF(129°C)[b]	—	0.85
VTE(129°C)[c]	—	0.73
MSF(90°C)[b]	—	0.89
Reverse Osmosis[d]	0.255	0.95
Electrodialysis[d]		
Water Type[e] #1	0.27	—
#2	0.15	—
#3	0.19	—
#4	0.34	—

[a]Source: Larson and Associates, 1979.

[b]Multistage flash distillation (energy from oil-fired boiler; steam at $0.98/MBtu and electrical energy at $0.0344/kWhe).

[c]Vertical tube evaporator distillation (energy from oil-fired boiler).

[d]Electrical energy for membrane processes at $0.025/kWhe.

[e]Compositions of water types #1 through 4 are given in Table 5-35.

Table 5-34. Final Water Costs for Desalted Water: First Quarter, 1979[a]
(costs in $/kgal)

Feedwater	Low Salinity (2,000-5,000 ppm)			High Salinity (35,000 ppm)		
Process						
Plant Capacity (mgd)[b]	----------------------------			1.0	5.0	100.0
Distillation						
MSF(129°C)[c]	----------------------------			6.41	4.44	2.86
VTE(129°C)[d]	----------------------------			5.77	3.93	2.26
MSF(90°C)[c]	----------------------------			6.73	5.23	f
Plant Capacity (mgd)	1.0	5.0	25.0	1.0	5.0	
Reverse Osmosis	1.37	1.07	0.95	4.61	4.31	
Plant Capacity (mgd)	1.0	5.0	25.0	-------------------------		
Electrodialysis						
Water Type[e] #1	1.32	1.17	1.00	-------------------------		
#2	1.10	0.94	0.78	-------------------------		
#3	1.00	0.86	0.71	-------------------------		
#4	1.31	1.15	0.98	-------------------------		

[a]Source: Larson and Associates, 1979.

[b]mgd = million gallons per day.

[c]Multistage flash distillation.

[d]Vertical tube evaporator distillation.

[e]Compositions of water types #1 through 4 are given in Table 5-35.

[f]Information unavailable.

Table 5-35. Chemical Compositions of Typical Brackish Waters[a]

Chemical Composition (ppm)	Water Type #1	#2	#3	#4
Sodium (Na)	886	125	630	900
Calcium (Ca)	118	316	116	250
Magnesium (Mg)	72	69	15	70
Chloride (Cl)	131	67	1054	1450
Sulfate (SO_4)	1943	900	115	590
Bicarbonate (HCO_3)	473	357	78	210
Hardness as $CaCO_3$	590	1073	354	912
Manganese (Mn)	2	0.10	0	0.1
Fluoride (F)			2	
Iron (Fe)	2	1.0	0	0.4
Potassium (K)	16	13	0	5
Nitrate (NO_3)	6.3	19	9	1
Silicate (SiO_3)			17	
Total Dissolved Solids	3648	1800	2076	3475
pH	7.6	7.9	8.1	7.3
Temperature	70	70	70	70
Organics (Chemical Oxygen Demand)	10	7.9		7

[a]Source: Larson and Associates, 1979.

site. Use of waste brine may reduce or eliminate desalination plant effluent disposal costs and may reduce solar pond costs through reduction in evaporation pond area. However, the technical and economic feasibility of such a coupling is highly site-dependent, and is not considered further in this report.

The thermal, mechanical and electrical requirements for the various desalination processes may be satisfied by a solar pond alone; a solar pond in conjunction with another energy source; or another energy source alone.

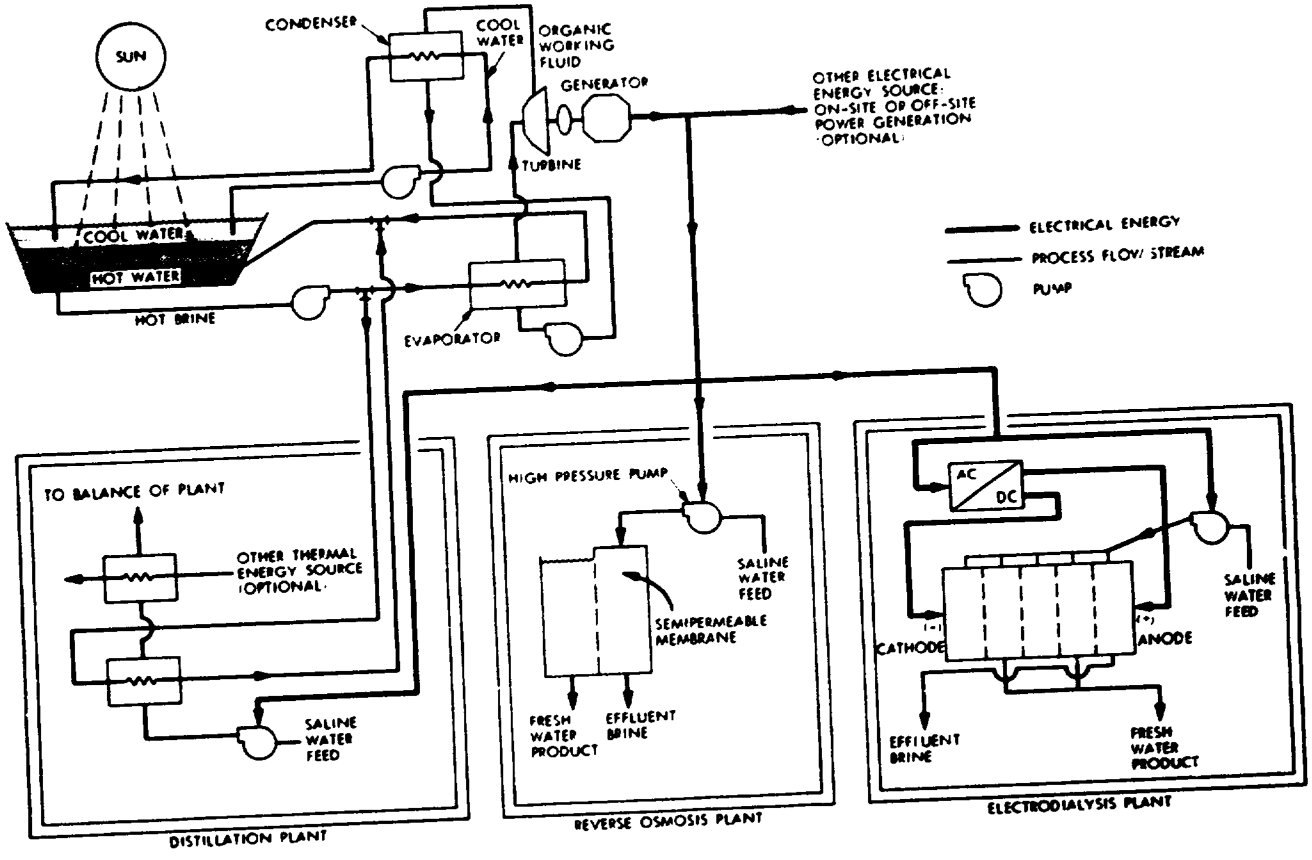


Figure 5-27. Solar Pond Desalination Plant: Thermal and Electrical Energy Path

The thermal energy source must be located on-site due to energy transport loss considerations, whereas a solar pond or other source of electrical energy may be located either on-site or off-site with energy fed through the local power grid. A discussion of some of the considerations involved in plant design resulting from different configurations follows. Note that solar pond-desalination plant cost optimization will consider a multitude of factors including seasonal water demand, cogeneration incentives, site specific pond and plant costs, and conventional energy costs.

5.5.3.1 Membrane Desalination: Reverse Osmosis and Electrodialysis.

5.5.3.1.1 On-site Solar Pond for Electrical Energy. It is possible to use an on-site solar pond to provide electrical energy for membrane desalination. However, as for all on-site applications of solar ponds, siting criteria and constraints over and above that required for the application process must be satisfied. It is not possible to estimate the fraction of sites at which membrane desalination plants are likely to be installed that would also satisfy solar pond siting constraints and criteria without a site-by-site examination.

The electrical output from a solar pond power plant will usually exhibit some seasonal variance due to seasonal fluctuations in climatic conditions. Judicious selection of design and operating specifications can be effective in reducing the ratio of peak-to-average power output. However, constraining the pond to minimal power output variance may result in a modest reduction in annual-average pond electrical output.

System design optimization will probably result in sizing the solar pond so that the power generation rate is greater than the rated demand of the desalination plant during portions of the year. The excess electrical energy can be diverted to an alternate on-site use or to the power grid during periods of high solar pond power generation. If the solar pond output is less than the desalination plant electrical demand during any portion of the year, desalination plant will be operated at less than rated plant capacity. These concepts, known as "clipping," are shown graphically in Figure 5-28. It should be noted that seasonal variance of desalination plant output may be desireable to satisfy a varying water demand.

5.5.3.1.2 On-Site Solar Pond in Conjunction with Another Energy Source. Use of an on-site solar pond in conjunction with another energy source permits design without "clipping" of either solar pond or desalination plant output. A likely scheme would be for the desalination plant to operate at or near the peak solar pond electrical output rate. During the remainder of the year, the other energy source would provide sufficient energy to maintain desalination plant production at the rated plant output. This scheme could be modified to reflect utility-initiated incentives that would promote the use of the solar pond as an independently operated power plant supplying power into the grid.

5.5.3.1.3 Off-site Solar Pond. Use of an off-site solar pond simplifies site-selection criteria. Coupling the solar pond and desalination plant

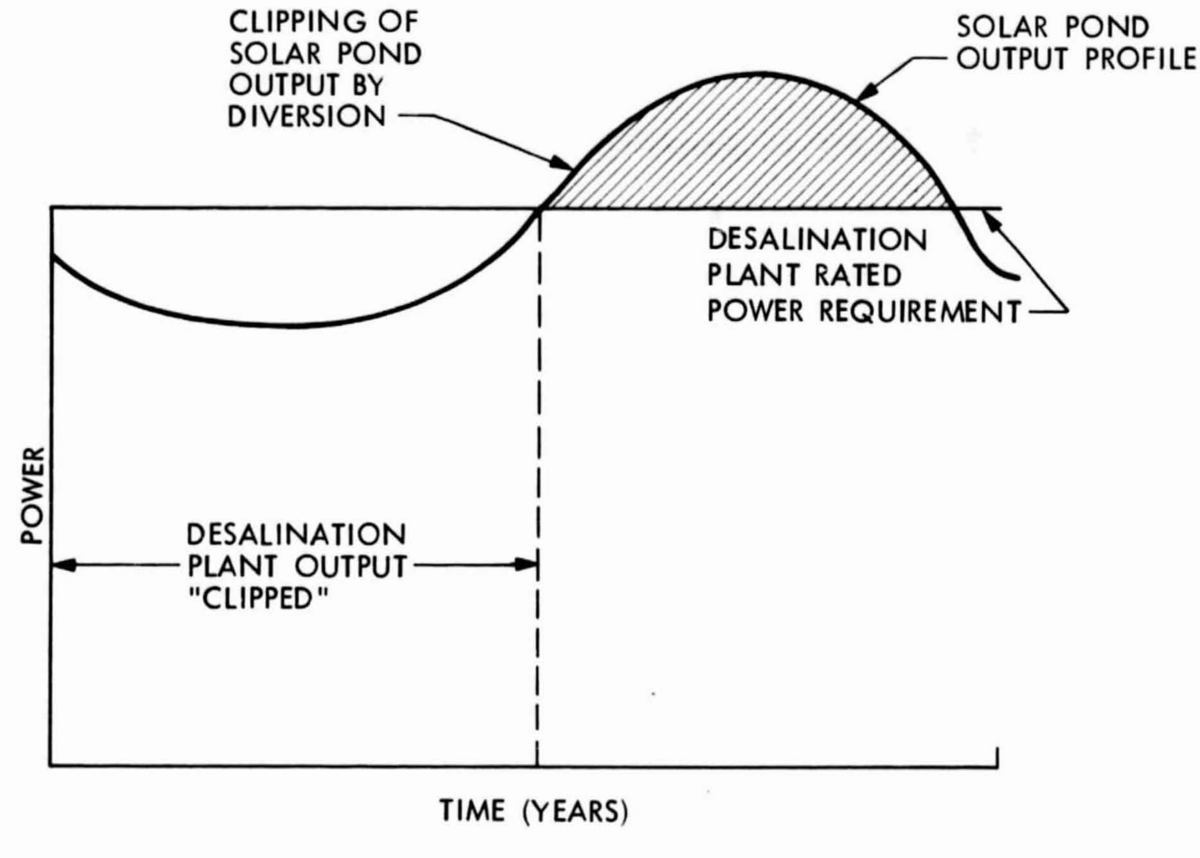


Figure 5-28. Clipping of Solar Pond and Desalination Plant Output

through the local power grid eliminates all "clipping" considerations and places analysis of the solar pond applicability and potential under the heading of solar pond applicability and potential for power generation.

5.5.3.2 Distillation Desalination. Use of a solar pond for distillation is technically feasible for either thermal or electrical process energy requirements. The considerations are somewhat more complex than for membrane desalination where only electrical energy is needed. The following paragraphs detail some of the aspects of coupling a solar pond with a moderate or high temperature distillation plant. The processes included in Tables 5-30 through 5-34 are multiple stage flash at 194 and 266°F and vertical tube evaporation at 266°F. Lower temperature distillation (ca. 167°F) is technically feasible, but at somewhat lower process energy efficiency and higher costs. Cost estimates for lower temperature distillation are not available on as complete a basis as for higher temperature distillation.

5.5.3.2.1 On-site Solar Pond for Thermal Energy. It is not generally feasible for a solar pond to serve as a sole energy source for thermal energy for moderate (194°F) or high (266°F) temperature distillation. A more attractive option is to couple a solar pond with a low-temperature (ca. 167°F) distillation plant. The "clipping" considerations apply to thermal applications as well as to electrical.

5.5.3.2.2 On-site Solar Pond for Thermal and Electrical Energy. Use of solar ponds for distillation thermal and electrical energy entails the considerations previously discussed for coupling of an on-site solar pond with a membrane desalination plant as well as those factors discussed in the preceeding paragraphs regarding thermal energy supply. In addition, the profiles of thermal and electrical energy production from a pond operating at a nominal temperature of approximately 167°F will differ significantly in shape due to seasonal variance of the thermal-to-electric conversion efficiency which is determined by the annual ambient and storage zone temperature profiles. Therefore, a solar pond that supplies both thermal and electrical power to a distillation plant will require other energy sources for both thermal and electrical power in order to maintain constant desalination plant output.

5.5.4 Potential for Solar Ponds in Desalination

Projections for the year 2000 of the regional distribution of desalination demand are shown in Table 5-36. The data was obtained by redistributing projections (Rothmerel, 1972) for demand in 20 hydrogeologic regions among the 12 regions as defined in Section 3.1. The redistribution is based solely on land area assignments and does not reflect more precise considerations of desalination demand distribution. Data was insufficient for projections of demand for Alaska, Hawaii, and Puerto Rico.

Projections for the solar pond potential as an energy source for desalination are shown in Tables 5-37 and 5-38 for low- and high-salinity feedwater, respectively. The values shown are the total area dedicated to solar ponds for desalination based on pond-plant coupling configurations as described below.

Table 5-36. Projections of Year 2000 Regional Distribution of Desalination Market[a]

Region	Desalted Water Demand: High-Salinity Feedwater mgd	m^3/s	Low-Salinity Feedwater mgd	m^3/s
Southwest	811.4	35.6	113.8	4.99
Salt Lake	576.0	25.3	99.5	4.36
Red River	322.8	14.2	81.7	3.58
Pacific Northwest	28.4	1.3	10.2	0.45
Black Hills	0.0	0.0	68.2	1.99
Great Lakes	0.0	0.0	92.6	4.06
Tennessee	66.3	2.9	27.8	1.22
Gulf Coast	186.2	8.2	18.1	0.79
Atlantic Northeast	11.9	0.5	4.4	0.19
Alaska	b	b	b	b
Hawaii	b	b	b	b
Puerto Rico	b	b	b	b

[a]Source: Rothmerel, 1972.

[b]Insufficient data available for estimation of desalination market in Alaska, Hawaii, and Puerto Rico.

The energy requirement for desalination of low-salinity feedwater is assumed to be 9.5 MJe/m^3, which represents an approximate average of the electrodialysis and reverse osmosis values reported in Table 5-18. The rate of solar pond electrical power generation reported in Section 3.2.4 is for operation at a constant lower convecting zone temperature, and thereby represents a summer-peaking pond. It is assumed that, as an approximation, the rate of power generation would not be significantly changed by operation of the pond in a more-levelized output mode. Therefore, the projections are equally applicable to an on-site solar pond coupling with minimal clipping of pond output and no other energy source, and to an off-site pond coupling. As shown in Table 5-37, the United States' potential for solar ponds for desalination of low-salinity feedwater amounts to 141.7 km^2 based on 100% market penetration and a water demand of 516.3 mgd. The total energy required for this demand is 215 MWe, corresponding to 0.02 quad/yr of fossil fuel.

Table 5-38 presents pond area requirements for a high-salinity feedwater desalination plant. Based on distillation plants, the United States' potential for solar ponds for desalination of high-salinity feedwater is 516.2 km^2, yielding 20359.6 MWt (0.61 quad/yr). Alternatively, using reverse osmosis technology, the pond area required is 1358.0 km^2, yielding 3168 MW_e (0.29 quad/yr). The computations for the high-salinity reverse osmosis plants assume an energy requirement of 36.1 MJe/m^3 and apply to the

Table 5-37. Projection of Year 2000 Low-Salinity Feedwater Desalination Solar Pond Area Requirements

Region	Desalted Water Demand mgd	Desalted Water Demand m^3/s	Energy Demand at 9.5 MJe/m^3 MWe	Pond Output Rating We/m^3	Pond Area km^2
Southwest	113.8	4.99	47.4	3.12	15.2
Salt Lake	99.5	4.36	41.4	2.31	17.9
Red River	81.7	3.58	34.0	1.94	17.5
Pacific Northwest	10.2	0.45	4.3	1.43	3.0
Black Hills	68.2	2.99	28.4	1.01	28.1
Great Lakes	92.6	4.06	38.6	0.84	46.0
Tennessee	27.8	1.22	11.6	1.61	7.2
Gulf Coast	18.1	0.79	7.5	1.80	4.2
Atlantic Northwest	[a]	[a]	1.8	0.68	2.6
Alaska	[a]	[a]	[a]	0.00	0.0
Hawaii	[a]	[a]	[a]	2.71	[a]
Puerto Rico	[a]	[a]	[a]	2.72	[a]
U.S. Total	516.3	22.63	215.0		141.7

[a]Insufficient data available for estimation of desalination market in Alaska, Hawaii, and Puerto Rico.

same coupling configurations as described above. The pond-plant coupling chosen for the distillation plants is based on assumption of lower temperature operation than is now economically optimal with conventional energy sources. It is assumed that technological improvements will allow for reduction of thermal energy requirements at 167°F to 232 MJt/m^3 (10 lb/kBtut). The coupling configuration specified here is for a solar pond to provide constant temperature, variable load thermal energy. The remaining thermal energy requirement and plant electrical requirements are supplied by another energy source. Although this coupling configuration is a reasonable choice, it does not necessarily represent the optimal coupling of a solar pond with a distillation plant. In fact, the optimal coupling configuration chosen is likely to vary as a function of site-dependent considerations.

Table 5-38. Projection of Year 2000 High-Salinity Feedwater Desalination Solar Pond Area Requirements

Region	Desalted Water Demand, mgd	Desalted Water Demand, m^3/s	Reverse Osmosis: Energy Demand at 36.1 MJe/m^3, MWe	Reverse Osmosis: Pond Output Rating, We/m^2	Reverse Osmosis: Pond Area, km^2	Distillation: Energy Demand at 232 MJt/m^3, MWt	Distillation: Pond Output Rating, Wt/m^3	Distillation: Pond Area, km^2
Southwest	811.4	35.5	1283.3	3.11	412.6	8247.5	52.95	155.8
Salt Lake	576.0	25.2	911.0	2.31	394.4	5854.8	36.53	160.3
Red River	322.8	14.1	510.6	1.94	263.2	3281.1	35.07	93.6
Pacific Northwest	28.4	1.2	44.9	1.43	31.4	288.7	22.92	12.6
Black Hills	0.0	0.0	0	1.01	0.0	0	16.00	0.0
Great Lakes	0.0	0.0	0	0.84	0.0	0	13.49	0.0
Tennessee	66.3	2.9	104.9	1.61	65.1	673.9	28.62	23.5
Gulf Coast	186.2	8.2	294.5	1.80	163.6	1892.6	31.75	59.6
Atlantic Northeast	11.9	0.5	18.8	0.68	27.7	12.1	11.17	10.8
Alaska	[a]	[a]	[a]	0.00	0.0	[a]	0.00	0.0
Hawaii	[a]	[a]	[a]	2.71	[a]	[a]	47.59	[a]
Puerto Rico	[a]	[a]	[a]	2.72	[a]	[a]	48.43	[a]
	2003.0	87.6	3168.0		1358.0	20359.6		516.2

[a]Insufficient data available for estimation of desalination market in Alaska, Hawaii, and Puerto Rico.

SECTION 6

SOLAR POND ECONOMICS

This portion of the report develops cost estimates for the energy delivered from solar ponds, and compares these cost estimates with energy costs from alternatives. Data are developed for each region and application on solar pond system costs and performance, tax rates, investment tax credits, escalation rates for input prices, depreciation schedules, etc. This information is summarized in Section 6.2, and is utilized in the Energy Systems Economic Analysis (ESEA) model (described in Section 6.1) to derive estimates of solar pond output cost by region and application. These energy output costs, and their sensitivity to system and economic assumptions, are presented in Section 6.3. Conventional energy costs are indicated in Section 6.4, and a final section compares conventional and solar pond energy costs.

6.1 COST MODEL DESCRIPTION

This financial analysis determines busbar energy cost (BBEC), which is the minimum price which solar pond energy users would have to pay in order for investors to cover solar pond system costs. Energy charges will vary with the assumptions made about pond construction costs, system lifetime and performance characteristics, application-related specifics, and the financial environment in which the solar pond system is operated.

The procedure for deriving the cost of delivered energy is discussed in the remainder of this section. Basically, delivered energy cost (BBEC) may be calculated as

$$BBEC = \frac{LCC \cdot CRF}{CAP \cdot CF \cdot 8760}$$

where

BBEC = busbar energy cost
LCC = solar pond life-cycle costs
CRF = capital recovery factor
CAP = system capacity
CF = capacity factor

A discussion of these variables and their derivation is included in the following subsections.

Before describing the methods used to aggregate costs and energy output, a discussion of the concept of discounting will be helpful. The patterns of cost and revenue flow are very important to investors. Uncertainty, the possibility of investment obsolescence, alternative uses of investment dollars and other such factors make options with immediate and rapid returns more attractive than options for which the same returns occur more slowly. Thus, the shape of a net income curve is as important as the area beneath it. For example, investors would view a system that generates $70,000 in revenues the first year and negligible benefits thereafter differently than they would a system which generates $7,000 every year for 10 years, or a system providing

$70,000 only in the tenth year, even though all three systems provide $70,000 in revenues over their usable lifetime. To account for these differences, financial analysis utilizes the concept of discounting. The costs and revenues occurring in any period "t" are weighted by the discounting term $(1 + R)^{-t}$, where R is the investor's discount rate. This term indicates that future revenues are less desirable compared to present ones, and future taxes are not as burdensome as current payments. Discounting allows numerous cost outflows and revenue inflows, which occur in different time periods, to be aggregated into a single number.

6.1.1 Solar Pond Life-Cycle Costs

Solar pond system costs were derived using a financial model (ESEA) developed at JPL (Slonski, 1979). This model calculates life-cycle system costs based upon the size and timing of costs outflows and assumptions about financial considerations such as taxes and depreciation.

The total costs of the system will be the summation of several terms. The basic formula for calculating life cycle costs is:

Life cycle costs = capital investment

- tax reduction from depreciation

- tax reduction from investment tax credits

+ recurrent costs

+ income tax payments

+ miscellaneous expenses

The initial investment, I, is described in Section 6.2. Each of the remaining terms is translated into a numerical formula below. The variables that will be utilized in this discussion are:

(1) Initial capital cost (I).

(2) Discount rate or rate of return (R).

(3) System lifetime (T, in years).

(4) Depreciation rate (D).

(5) Investment tax credit rate (ITC).

(6) Tax rate (TR).

(7) Annual recurrent costs (C_j).

(8) Escalation rate for recurrent costs (E_j).

(9) Miscellaneous expense rate (MISC).

6.1.1.1 Tax Reduction from Depreciation

This requires calculating a depreciation rate, multiplying the rate by the capital investment to determine total depreciation, and then multiplying total depreciation by the tax rate to derive the amount of tax savings from depreciation. Depreciation may be calculated in a number of ways and involves the lifetime of the system and the discount rate used by the investor. For straight-line depreciation methods, the depreciation rate would be 1/T each year. Since depreciation accrues annually over the accounting life of the investment, the present day equivalent of such a depreciation rate (D) may be expressed as:

$$D = \frac{1 - (1+R)^{-T}}{T \cdot R}$$

However, most private corporations, for tax purposes, use a depreciation rate that reflects the fact that an investment depreciates most rapidly in the initial years. The depreciation method used in this study is the sum-of-the-years-digits method; a declining proportion of the investment is amortized each year. For example, an investment with a 10-year life has a sum-of-years of 1+2+3+ ... +9+10 = 55; 10/55 is amortized the first year, 9/55 the second year, and so on until 1/55 is depreciated in the final year. This pattern of depreciation has a present day equivalent depreciation rate of:

$$D = \frac{2 \cdot \left[T - \frac{1 - (1+R)^{-T}}{R} \right]}{T \cdot (1+T) \cdot R}$$

Once a depreciation method is chosen, the depreciation rate may be combined with the user tax rate and the capital investment to determine the present value of the income tax savings:

Tax reduction from depreciation = TR • D • I

The solar pond cost model uses the sum-of-the-years-digits depreciation method.

6.1.1.2 Tax Reduction from Investment Tax Credits

If a tax credit for the new system exists, it reduces the tax burden by a factor ITC:

Tax reduction from investment tax credit = ITC • I

6.1.1.3 Recurrent Costs

This category includes all the recurrent costs (O&M, consumables, etc.) associated with system operation throughout its lifetime. Since

the various costs could escalate at different rates, and these rates do not necessarily coincide with the discount rate, it will be necessary to escalate costs separately before discounting them to present-day dollars. If C_j represents annual recurrent costs (escalated from base-year dollars to dollars in first year of commercial operation) and E_j is the escalation rate (where subscript j denotes various recurrent costs), the general formula for a constant amount of recurrent costs is given below. C_j represents the annual cost of parasitic power or operation and maintenance; the remainder of the right-hand side adjusts this cost into current dollars.

$$\text{Recurrent Costs} = \sum_j C_j \cdot \frac{1 + E_j}{R - E_j} \cdot \left[1 - \left(\frac{1 + E_j}{1 + R}\right)^T\right]$$

$$(j = \text{fuel, O\&M})$$

6.1.1.4 Income Tax Payments

Income tax payments are based on an adjustment to the amortized investment which reflects the pre-tax revenue necessary to amortize a given amount with after-tax dollars. The adjustment is computed using the equation

$$\text{Adjustment} = \frac{1}{(1 - TR)} (1 - TR \cdot D - ITC) \cdot I$$

where D is the depreciation factor (described in subsection 6.1.1.1). The income tax payments are then

$$\text{Income Tax Payments} = \text{Adjustment} \cdot TR$$

6.1.1.5 Miscellaneous Expenses

Other payments, such as property taxes and insurance premiums, may be approximated by a constant multiple (MISC) of the initial capital cost.

$$\text{Miscellaneous expenses} = MISC \cdot I$$

6.1.2 Capital Recovery Factor

The capital recovery factor converts life cycle costs into a uniform annual cost stream. The equation is

$$CRF = \frac{R}{1 - (1 + R)^{-T}} \qquad R \neq 0$$

and

$$CRF = \frac{1}{T} \qquad R = 0$$

6.1.3 Calculating Solar Pond Energy Costs

As mentioned previously, energy costs may be derived using the equation:

$$BBEC = \frac{LCC \cdot CRF}{CAP \cdot CF \cdot 8760}$$

From the discussion in sections 6.1.1 and 6.1.2, life-cycle costs may be calculated using the formula

$$LCC = I - TR \cdot D \cdot I - ITC \cdot I$$

$$+ \sum_j C_j \cdot \frac{1 + E_j}{R - E_j} \cdot \left[1 - \left(\frac{1 + E_j}{1 + R}\right)^T\right]$$

$$+ \frac{1}{1 - TR} \cdot (1 - TR \cdot D - ITC) \cdot I$$

$$+ MISC \cdot I$$

These life-cycle costs are multiplied by the capital recovery factor to get an annual cost estimate. The resultant annual cost is divided by annual energy output (system capacity, multiplied by capacity factor and the number of hours in a year) to obtain energy output costs.

6.2 INPUT DATA FOR FINANCIAL ANALYSIS

6.2.1 Capital Costs

The capital investment associated with installing a solar pond is listed in Table 6-1. Pond subsystem cost items (land, salt, excavation, etc.), heat distribution subsystem costs and power conversion subsystem costs are included.

For thermal applications, a 1-acre pond (surface area) with a depth of 15.5 ft is assumed. Four cases were examined, each of which represents a possible cost scenario. Case 1 is based on the following cost data: land at \$5,000/acre; excavation at \$1.96/m^3 (\$1.5/yd^3); diking at \$1.57/m^3 (\$1.2/yd^3); 5,740 tons of salt at \$0.03/kg (\$30/ton); liner installed at \$7.53/m^2 (\$0.7/ft^2); and a lump-sum cost of \$25,000 for instrumentation and miscellaneous items. This is equivalent to a unit pond construction cost of \$75/m^2, a realistic estimate as compared with the recently built TVA and Gray Mountain ponds. Cost reduction is possible depending on the resources available at specific sites and is reflected in Cases 2, 3 and 4. Cases 2 through 4 omit salt costs; this is an option if local salts are available at no cost, or if brine waste pools exist (as is the case with the Red River Chloride Control Project and some industrial processes, such as geopressurized gas exploration and olive processing). Cases 3 and 4 assume labor costs of \$50,000/pond acre rather than \$120,000. This assumption is valid if minimal diking or

Table 6-1. Solar Pond Capital Costs

A. Thermal Applications (1-acre pond, 15.5-ft depth)

Cost Item	Case 1	Case 2	Case 3	Case 4
Land (10^3\$)	5	5	5	0
Excavation/Diking (10^3\$)	120	120	50	50
Salt (10^3\$)	110	0	0	0
Liner (10^3\$)	45	45	45	0
Instrumentation & Miscellaneous (10^3\$)	25	25	25	25
Total Pond Construction (10^3\$)	305	195	125	75
Unit Pond Construction (\$/m^2)	75	48	31	19
Heat Distribution Subsystem (\$/m^2)	12	12	12	12
Total (\$/m^2)	87	60	43	31

Relevant Cost Ranges:

Land	0-25	(10^3\$/acre)
Excavation	50-120	(10^3\$/acre)
Salt	0-110	(10^3\$/acre)
Liner	0-45	(10^3\$/acre)
Water	0-3	(10^3\$/acre)
Heat Distribution	12-35	(\$/m^2)

B. Electric Power Production

Cost Item	Wet Site Salton Sea 250-Acre 5-MWe Plant	Dry Site Bristol Lake 250-Acre 5-MWe Plant	Wet Site Salton Sea 26400-Acre 600-MWe Plant
Pond Subsystem (10^6\$)	14-18	9-18	558
Power Generating Subsystem (10^6\$)	8	8	540[a]
Total Solar Pond System (10^6\$)	22-26	17-26	1,098

[a]540 is applicable only to Daggett: for other sites, power generation subsystem cost is proportional to the site's net electric power output.

excavation is needed, which is again true of some existing ponds and of sites where existing topography can be used. Case 4 omits liner and land costs; some areas have deposits of usable clays, and the underlying soils are impermeable, so that installation of a pond would not jeopardize freshwater supplies; in such instances liners may be unnecessary. A unit cost of $\$12/m^2$ is assumed for the heat distribution subsystem in all cases. It should be noted that the $\$/m^2$ unit is somewhat artificial but the cost estimate is based on the study presented in Section 4.2.

For electric power applications, three cases were examined. The cost estimates are based on those made by Ormat Turbines, Ltd. for the Salton Sea feasibility study (Ormat Turbines, Ltd., 1981). As shown in Table 6-1, the first case is associated with a 250-acre solar pond constructed within the Salton Sea (wet site). Pond subsystem cost is estimated at $14 million if dike construction material is obtained from within the sea, and at $18 million if onshore material is required. The second case is associated with a 250-acre pond constructed on the dry lake bed of Bristol Lake, which is underlain by layers of clay and salts and covered with a surface layer of white crustal salts. Dryland construction is less expensive than in-sea construction, and the construction cost is estimated at $9 million if a liner is not required and at $18 million if a plastic liner is installed. These two cases give cost estimates for a 250-acre experimental pond facility. The third case is regarded as representative of a commercial solar pond power plant which utilizes 26,4000 acres of solar ponds and, under the Salton Sea climatic conditions, is expected to have a nominal capacity of 600 MWe. As can be seen from Table 6-1, a significant fraction of the total power plant construction cost is ascribed to the power generating subsystem, and this fraction increases as the size of the power plant gets larger. Included in the pond subsystem cost are costs of such items as solar ponds, evaporation ponds, brine make-up and circulation equipment, cooling and flushing subsystems, water treatment plant, control equipment, engineering administration, etc. Power generating subsystem cost includes the costs of turbogenerators, heat exchangers, feed pumps, materials, engineering administration, etc. (Ormat Turbines, Ltd., 1981. See also Appendix L). For the 26,400-acre pond case, the estimate of $540 million for the power generating subsystem applies only to the Southwest region. For other regions with lower energy yields, the power generating subsystem cost is scaled down according to the region's net electrical power output, as given in Table 6-2.

There is one important caveat to these capital costs. Solar pond capital costs are assumed to be uniform across regions. This may introduce some bias to areas where initial conditions differ widely from those of the Salton Sea, where data was gathered. For example, extremely rocky land may raise excavation costs at a particular site in an area that looks attractive under this analysis. However, Salton Sea conditions were not felt to be unique as far as land and salt availability are concerned, so these costs are assumed to reasonably approximate those of a typical electricity-generating solar pond. There is some analysis of the sensitivity of energy costs to capital costs that should be carefully examined. This is not intended as a site-specific study, but rather to offer guidelines as to areas in which ponds might be economical.

Table 6-2. Energy Output[a]

A. Thermal Applications (1-acre pond, 15.5-ft depth)

Site	Energy Output (MWth)	Parasitic Power (We/m^2)
Southwest	0.256	0.47
Salt Lake City	0.187	0.35
Red River	0.183	0.35
Pacific Northwest	0.129	0.25
Black Hills	0.102	0.21
Great Lakes	0.090	0.19
Tennessee Valley	0.156	0.30
Gulf Coast	0.170	0.32
Atlantic Northeast	0.081	0.17
Alaska	-	-
Hawaii	0.234	0.44
Puerto Rico	0.238	0.44

B. Electric Power Production

Site	Capacity	
	250-acre pond, MW	26400-acre pond, MW
Southwest	3.1	332
Salt Lake	2.3	247
Red River	2.0	207
Pacific Northwest	1.4	153
Black Hills	1.0	108
Great Lakes	0.85	90
Tennessee Valley	1.6	172
Gulf Coast	1.8	192
Atlantic Northeast	0.69	73
Alaska	-	-
Hawaii	2.7	290
Puerto Rico	2.8	291

[a]See section 3.2.3 and 3.2.4 for a detailed discusssion.

6.2.2 Recurrent Costs

This cost category includes labor, consumables, maintenance, and other recurrent expenses (Table 6-3). For thermal applications, each acre of pond was assumed to require a nominal $10,000 per year in operation and maintenance costs.[1] These costs are assumed to escalate at a 9.3% nominal rate per year, which is a 2% real rate, as shown in Table 6-3. Thermal applications also required minor purchases of electric power to operate pumps and control equipment; these fuel costs and cost escalation rates varied by region [Data Resources, Inc., (DRI) 1981]. The regional electricity price is the Data Resources' price for the DRI region in which the selected solar pond site is located, translated into 1981 dollars. The escalation rate is an average of 1980 through 1990 and 1990 through 2000 rates from DRI. Data Resources, Inc. electricity prices were multiplied by annual parasitic power requirements (see Table 6-2, Column 2), 4047 (to convert from m^2 to acres), and 8760 (to convert from hourly to annual estimates). The results of these calculations are shown in the "Fuel Cost" column of Table 6-3.

Electric power production costs depended upon the system under study. The recurring costs associated with electric power production are categorized as shown in Table 6-3. Again, these cost estimates are based on those made by Ormat for the Salton Sea feasibility study (Ormat Turbines, Ltd., 1981), which in turn are based on Ormat's operating experiences with the Yavne and Ein Bokek ponds.

6.2.3 Financial Parameters

The system is assumed to have a usable life of 20 years, and is depreciated using an accelerated method (sum-of-years-digits). There is a 10% investment tax credit. Tax rates vary by region, and equal the sum of state and federal rates, less the product of state and federal rates (i.e., $TR = T_s + T_f - T_s \cdot T_f$, where $T_f = 46\%$ and T_s varies by region).

The discount rate varies by user. Thermal applications are discounted at a 20% nominal rate, which translates into a 12.5% real rate. Because utilities can float tax-free bonds to obtain funds, utilities are assumed to have a different discount rate than industry. Investor-owned utilities are assumed to have the following debt/equity structure:

Source of Funds	Capitalization Rate (%)	Rate of Return on Funding Source (%, real)
Debt	50%	3%
Preferred Stock	15%	3.5%
Common Stock	35%	6.5%

[1]This lump-sum assumption for annual O&M cost appears conservative in comparison with experience from existing U.S. ponds. However, specific O&M data are not available. The sensitivity of thermal energy cost to uncertainty in O&M cost is discussed in Section 6.3.1.

Table 6-3. Recurrent Costs

A. Thermal Applications

O&M: For all cases: $10,000/acre-year[a]

Region	Site	Fuel Cost $/yr	Fuel Escalation Rate (% nominal)
Southwest	Daggett	846	9.1
Salt Lake	Salt Lake City	534	9.0
Red River	Fort Worth	660	10.2
Pacific Northwest	Pendleton	450	9.1
Black Hills	Huron	408	8.2
Great Lakes	Madison	405	7.8
Tennessee Valley	Memphis	426	9.5
Gulf Coast	Jackson	684	8.6
Atlantic Northeast	Albany	473	7.3
Alaska	Fairbanks	-	-
Hawaii	Honolulu	792	9.1
Puerto Rico	San Juan	792	9.1

B. Electric Power Production[b]

Cost Item	Wet Site Salton Sea 250-Acre 5-MWe Plant	Dry Site Bristol Lake 250-Acre 5-MWe Plant	Wet Site Salton Sea 26400-Acre 600-MWe Plant
Manpower (10^3\$/yr)	396	396	-
Consumables (10^3\$/yr)	88	33	-
General Maintenance (10^3\$/yr)	30	30	-
Total O&M (10^3\$/yr)	514	459	14,120

[a]See footnote 1 of this section.
[b]See Ormat Turbine, Ltd., 1981.

To determine overall return, this structure is aggregated in the following manner:

Real return = (1-TR)(% debt)(return on debt)
+ (% preferred)(return on preferred)
+ (% common)(return on common)

This translates into about a 3.5% real rate of return, or an 11% nominal return. For municipal utilities, which were assumed to be 100% debt-financed, the nominal

Table 6-4. Financial Parameters

System Lifetime	20 years
Year of Dollar Estimate	1981 $
Depreciation Method	Sum-of-years-digits
Construction Time	2 years
Miscellaneous Expense Rate	2.25%
Investment Tax Credit Rate	10%
Tax Rate:	
Southwest	51%
Salt Lake City	48%
Red River	48%
Pacific Northwest	50%
Black Hills	46%
Great Lakes	50%
Tennessee Valley	49%
Gulf Coast	49%
Atlantic Northeast	51%
Alaska	-
Hawaii	49%
Puerto Rico	44%
Discount Rate:	
Investor-Owned Utilities	11.0% (nominal)
Municipal Utilities	11.0% (nominal)
Thermal Applications	20.0% (nominal)
Capital Recovery Factor:	
Electric Power Applications	12.6%
Thermal Applications	20.5%
Inflation Rate	7.2%
O&M Escalation Rate	9.3% (nominal)
Capital Escalation Rate	7.2% (nominal)

rate of return was also 11%. O&M costs escalated at a rate of 9.3%; capital had a 7.2% escalation rate. The inflation rate was assumed to average 7.2% per year. All costs were translated into 1981 dollars, and the financial parameters are summarized in Table 6-4.

6.2.4 Regional Energy Output

Thermal and electrical energy outputs by region are shown in Table 6-2. This table is derived from results of solar pond performance analyses as described in Section 3.2. Specifically, the thermal part of Table 6-2 is obtained from Table 3-3 of Section 3.2 using data listed under the "60°C Heat Extraction" column. The 60°C extraction temperature is appropriate for building space and domestic water heating as well as other thermal applications. The electrical part of Table 6-2 is obtained from Table 3-4 of Section 3.2 by taking the greater output figure of the two columns listed therein, as recommended in Section 3.2.4.

The financial comparison between regions is based on the same acreage of pond as far as energy output is concerned. As can be seen from Table 6-2, energy output varies significantly among the regions, caused primarily by the different insolation levels. This difference in regional energy output will be reflected in the cost of energy from solar ponds, as will be made clear in the sections that follow.

6.3 COSTS OF DELIVERED ENERGY FROM SOLAR PONDS

Data presented in Section 6.2 are used in the model described in Section 6.1 to derive estimates of the cost of delivered energy from solar ponds. These estimates, and their sensitivity to system and financial parameters, are discussed in this section. Thermal applications are examined first; the remainder of the section is devoted to electric power applications.

6.3.1 Thermal Applications

Figure 6-1 presents energy output costs for 1985-2000, by region, and based upon capital costs of $\$43/m^2$. The twelve regions analyzed fall into three general groups. Three regions (the Southwest, Hawaii, and Puerto Rico) had relatively low pond output costs. These energy costs varied from about \$11/MBtu up to about \$12/MBtu. Four other regions (the Tennessee Valley, Gulf Coast, Red River, and Salt Lake regions) had intermediate energy output costs. These energy costs varied from about \$14/MBtu to about \$19/MBtu.

A final group (the Great Lakes, Atlantic Northeast, and Black Hills regions) had the highest energy output costs, with the Pacific Northwest falling almost exactly on the middle between these last two groups. These groupings of output costs were basically due to differences in insolation patterns. Variations in insolation changed the expected energy output of a solar pond. However, within each region, energy costs vary almost insignificantly over time. This is because solar ponds have minimal recurring costs.

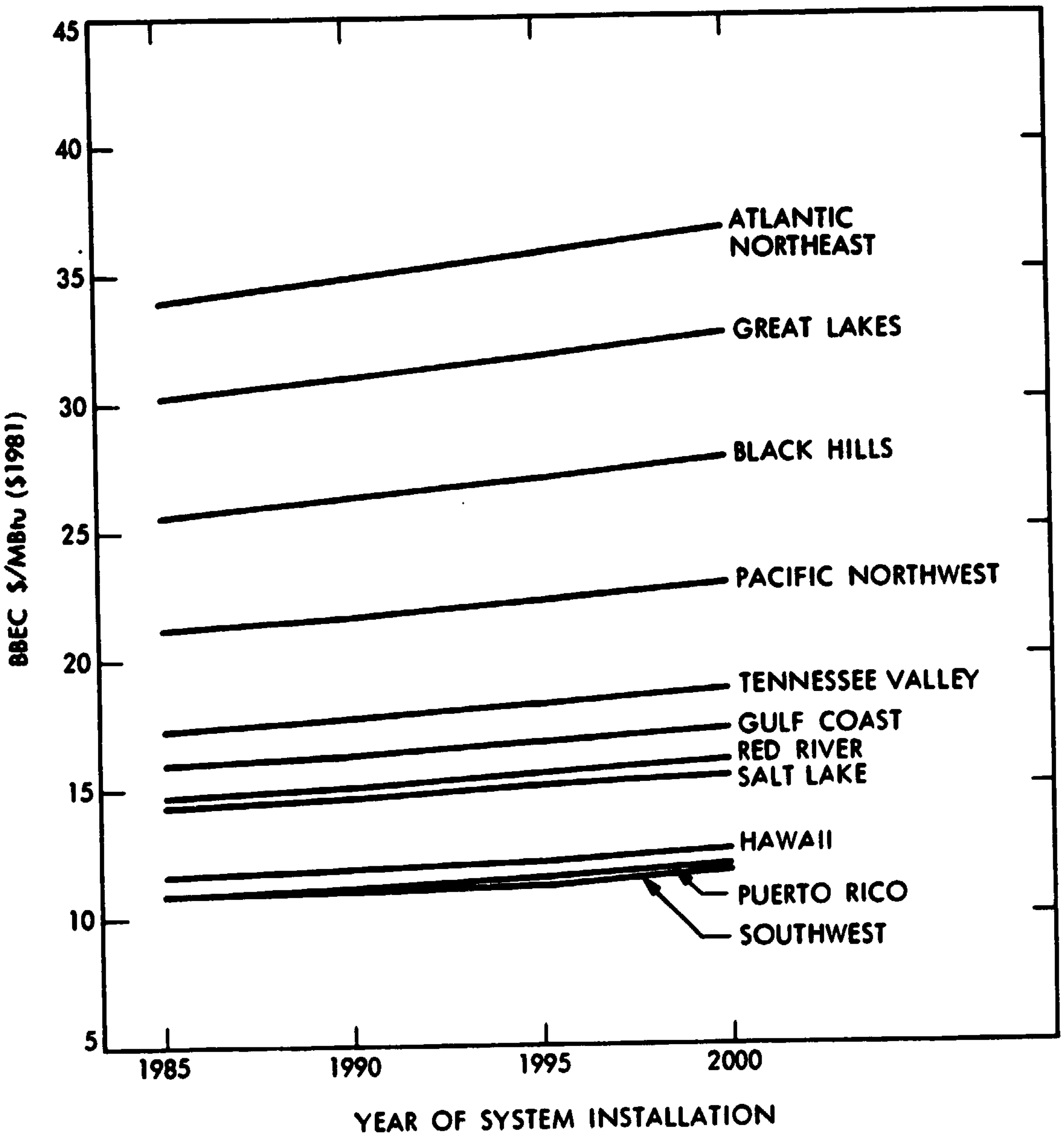


Figure 6-1. Solar Pond Energy Cost Estimates - Thermal (Capital Cost $43/m^2$, Discount Rate = 20%)

Figure 6-2 shows how these costs are affected if additional construction, diking, lining, or other capital costs are involved. The curves in Figure 6-2 are based upon a capital cost of $\$87/m^2$. The groupings of regions and their individual rankings remain the same, and energy costs vary insignificantly over time. However, energy output costs in each region and year are significantly increased. Whereas the lowest cost group had energy costs of \$11-12/MBtu with $\$43/m^2$ capital costs, these BBEC estimates increase to \$19-21/MBtu with $\$87/m^2$ capital costs.

Because most of the cost of a solar pond is the initial capital cost, it is important to determine how sensitive pond energy costs are to the initial capital cost. This is done in Figure 6-3. It is apparent that energy costs are strongly dependent upon the cost and quantity of capital inputs utilized. For example, in the least expensive group of regions (the Southwest, Hawaii, and Puerto Rico), a relatively inexpensive system (which utilizes no liner, and takes advantage of existing topography and brine deposits) would have an energy output cost of approximately \$9/MBtu. However, if a liner must be installed, salts must be purchased, or extensive excavation and diking must be undertaken, energy costs could reach as much as \$20/MBtu.

In addition to assessing the sensitivity of pond output costs to total capital cost, it is also useful to indicate how responsive busbar energy cost estimates are to changes in costs of components, such as land and salt. The cost of land must be considered when deciding whether to install a solar pond, and where to install it. The question which then arises is how significant is the cost of land. The cost range given in Table 6-1 is from free land (i.e., no opportunity cost) to land costing \$25,000 per acre. At \$25,000 per acre, land costs contribute $\$6.18/m^2$ to the total solar pond thermal system cost. Cases 1 through 3 (capital costs of \$87, \$60, and \$43 per m^2), presented in Figure 6-3, assume land costs of \$5,000/acre, or $\$1.24/m^2$. The effects of adding another $\$5/m^2$ to capital cost can be read from the graph in Figure 6-3. A change in the land portion of capital expenditures of nearly 5 times will increase the busbar energy costs approximately 6 to 8%.

The cost and availability of salt is also an important factor. Salt costs can vary from 0 to \$110,000 per 1-acre pond, thus having a greater impact than the cost of land. At \$110,000 per acre, salt costs $\$27/m^2$. This is exactly the difference in the capital cost of the solar ponds presented in Figure 6-3 and Table 6-1 as Case 1 and Case 2. Adding \$110,000 for salt to the capital costs given in Case 2 increases the capital costs by 45%, from $\$60/m^2$ to $\$87/m^2$. The corresponding energy costs in each region are increased by about 36%.

The attractiveness of a solar pond project will be strongly influenced by the discount rate chosen for project evaluation. All industrial applications have been analyzed with a 20% discount rate, but the effect of changing this rate needs to be understood. The higher the capital costs, the greater the influence of a discount rate change. Additionally, the changes are not linear for a fixed capital cost. Figure 6-4 illustrates what happens to energy cost if all other parameters are held constant while the discount rate varies from 8 to 32%. Numerical examples of the sensitivity and nonlinearity are shown in Figure 6-4 and Table 6-5.

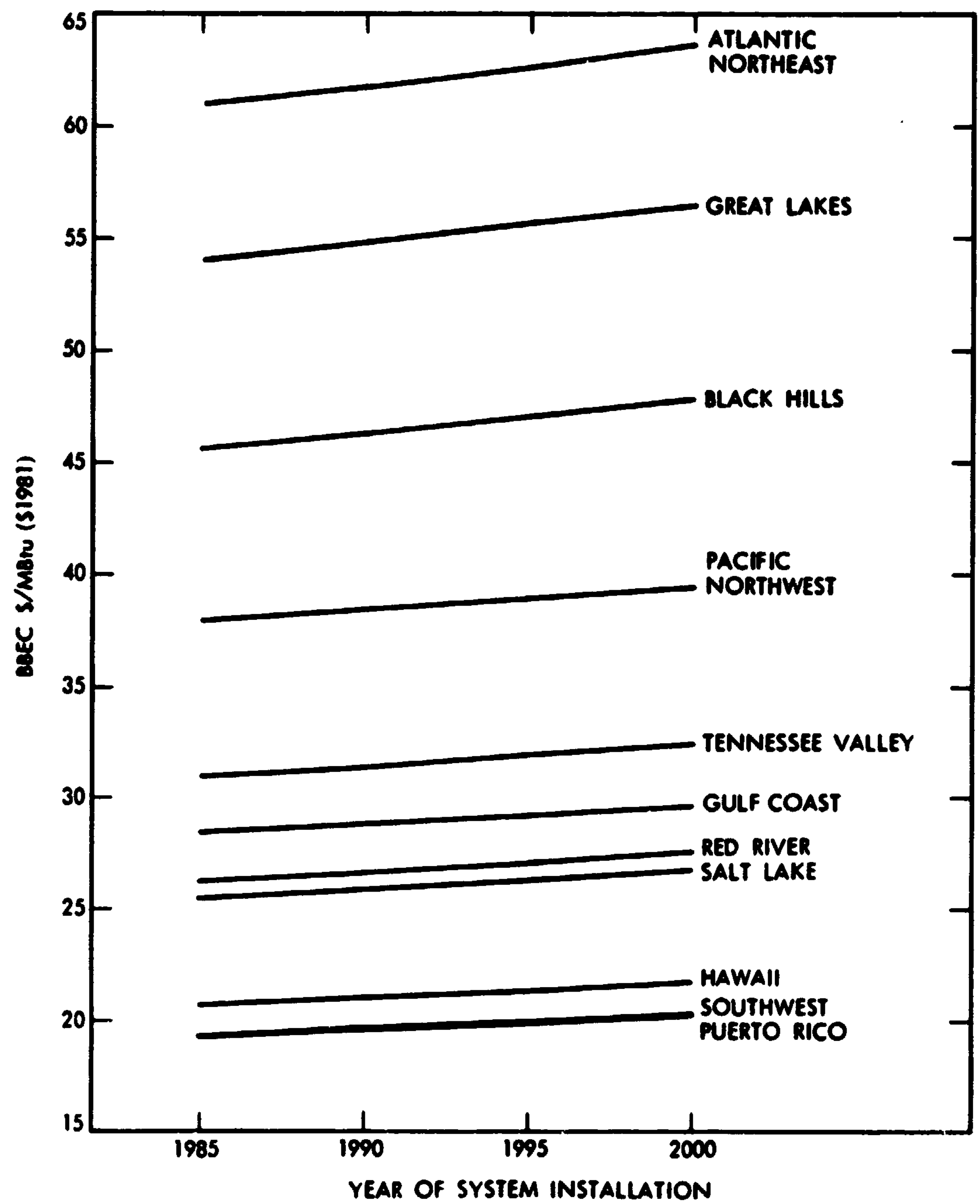


Figure 6-2. Solar Pond Energy Cost Estimates - Thermal (Capital Cost $87/m^2$, Discount Rate = 20%)

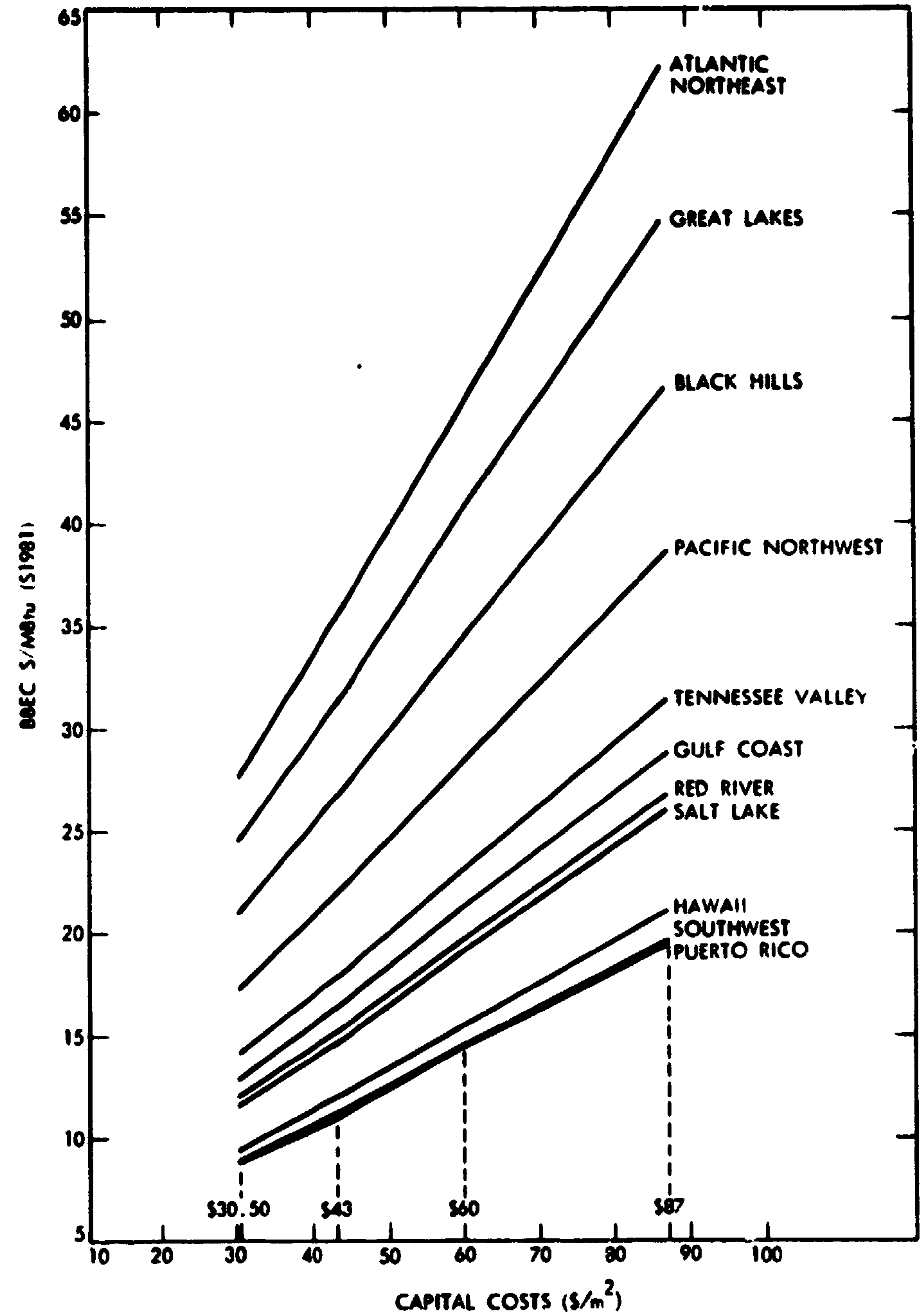


Figure 6-3. Sensitivity of Solar Pond Energy Cost Estimates to Capital Costs (Thermal Applications: 1990; Discount Rate = 20%)

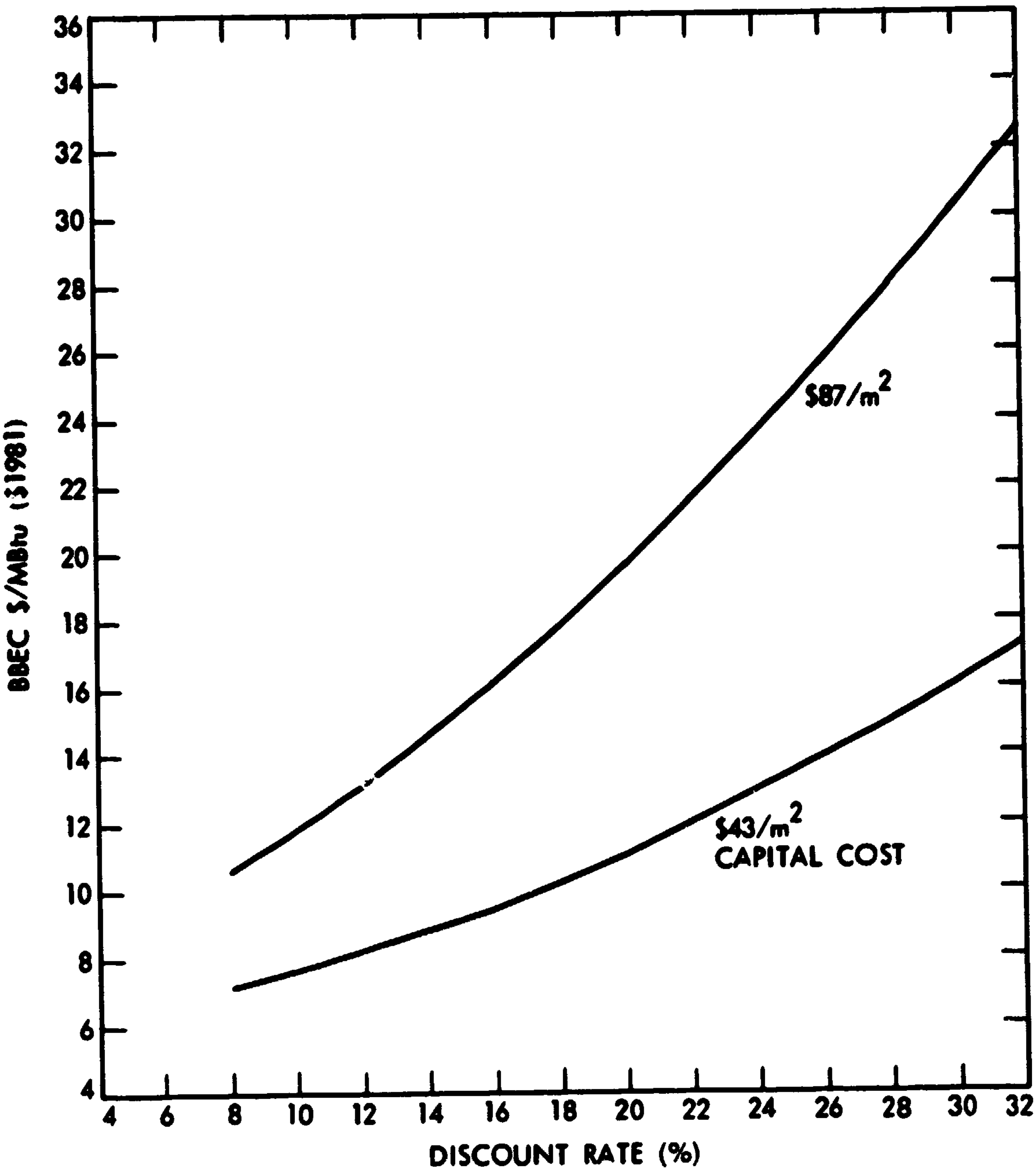


Figure 6-4. Sensitivity of Solar Pond Energy Costs to Discount Rate

Table 6-5. Sensitivity of Solar Pond Energy Costs to Changes in the Discount Rate (Thermal Application)

Rate Changes, from	to	Percent Change in Rate	Percent Change in Energy Cost at Capital Cost, $\$43/m^2$	$\$87/m^2$
8	16	100	33	52
10	20	100	45	66
16	32	100	81	102
20	30	50	45	54

All of the analysis for thermal applications thus far have been for industrial or commercial ownership. This necessitates using the discount rate with which industries would evaluate alternative projects and uses of funds. However, it is possible that not all thermal solar ponds would be installed by industrial users. A municipality may install one to generate heat for its own use or for resale through a municipal utility. A municipality would then be able to generate funds at a lower discount rate than private enterprise since it would be exempt from state and federal taxes. The assumptions which differ for municipal applications are given in Table 6-6.

Figure 6-5 gives the energy costs associated with a municipal thermal solar pond which becomes operational in 1990. The costs are based on the four capital cost cases outlined in Table 6-1 and can be compared with the industrial thermal application results given in Figure 6-3. Lowering the discount rate and dropping taxes made a substantial difference, with the cost range now going from \$6.04/MBtu for a $\$30.50/m^2$ capital cost in the Southwest to an energy cost of \$32.90/MBtu for an $\$87/m^2$ capital cost installation in the Atlantic Northeast Region, as opposed to a prior corresponding range of \$8.81/MBtu to \$61.75/MBtu.

Table 6-6. Financial Assumptions for Municipal Thermal Ponds[a]

Discount Rate	11%
State and Federal Taxes	None
Misc. Payments	2%
Investment Tax Credit	None
Depreciation	None
Discount Rate	11%

[a]All other assumptions remain the same as Thermal Applications parameters indicated in Table 6-4.

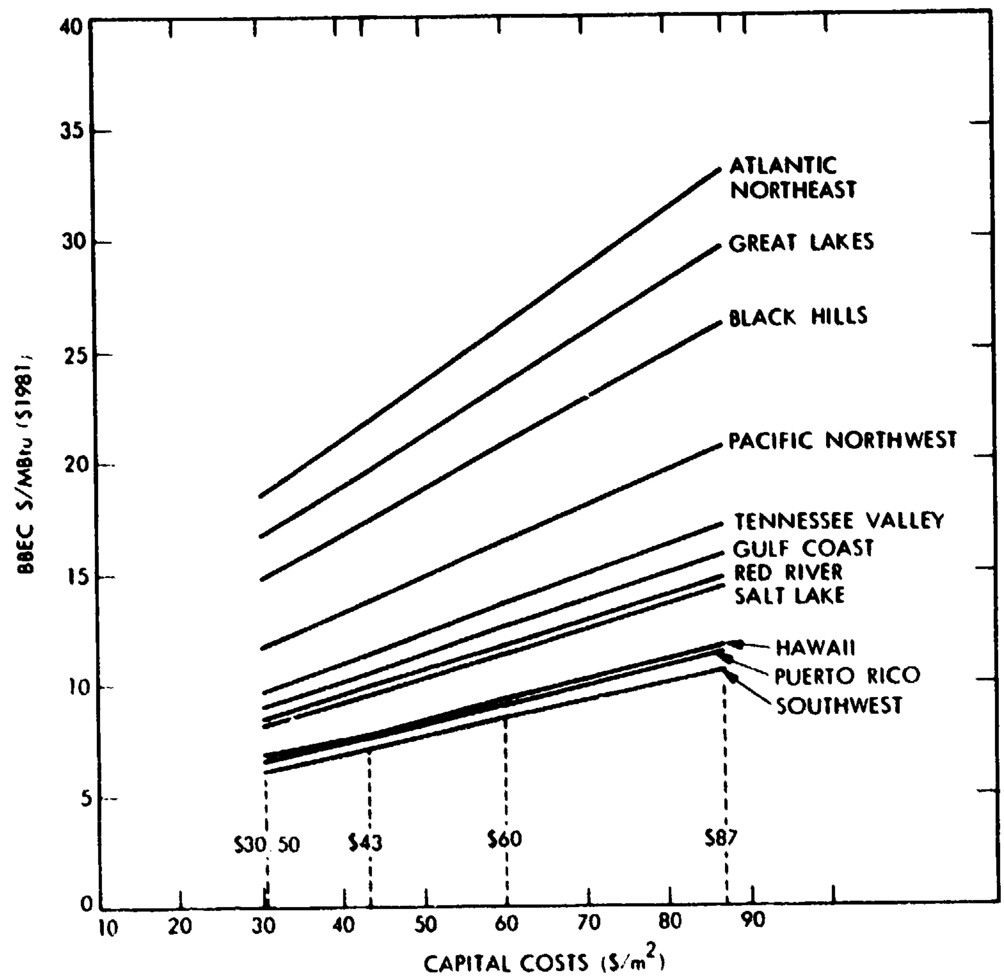


Figure 6-5. Solar Pond Energy Cost Estimates: Municipal Thermal Applications, 1990 (Discount Rate = 11%)

Available data for annual O&M costs are insufficient to provide details in support of the assumed lump-sum $10,000/acre-yr, although this figure is conservative compared with information gathered from the existing U.S. ponds. A sensitivity study was conducted to determine the contribution of annual O&M costs to the thermal energy cost. It was found that with an 11% discount rate and no taxes (the municipal case), every addition of $5,000 to the annual O&M costs adds $1.67 to the BBEC, and with a 20% discount rate and taxes (the industrial case), every addition of $5,000 to the annual O&M costs adds $1.38 to the BBEC. Thus, while the effect of O&M costs on the thermal energy cost is not insignificant, it is not nearly as dominant as capital cost.

6.3.2 Electric Power Applications

Electric power costs for the two 5-MW cases (wet site and dry site) are indicated in Figure 6-6. For the wet site, capital costs were assumed to vary from $22 to 26 million. Capital costs varied from $17 to 26 million for the dry site. Once again, three regions (the Southwest, Hawaii, and Puerto Rico) had relatively low energy output costs. However, the difference between this grouping of costs and the next group (Tennessee Valley, Gulf Coast, Red River, and Salt Lake regions) is not as pronounced as for the thermal applications. Even so, the energy output costs for 5-MW electric power plants are relatively high: energy output costs vary from around 200 mills/kWh to nearly 450 mills/kWh for these seven regions.

Cost estimates for the 600-MW electric power plant are shown in Figure 6-7. This figure shows estimates for the time period 1985 through 2000. Energy costs do not change significantly over this time period, because most of the cost of a solar pond is the initial capital investment. However, the energy cost varies significantly among regions, due to differences in regional energy output. For the three least costly regions (the Southwest, Hawaii, and Puerto Rico), energy costs varied from about 80 to 90 mills/kWh.

However, these cost estimates are significantly dependent upon the assumptions made. Figure 6-8 shows how sensitive energy output costs are to capital costs in the Southwest region for 1990. As capital costs increase from $2,000 to $4,000 per kilowatt installed, energy costs increase from 90 to 170 mills/kWh. That is, a 100% increase in capital costs translates into nearly a 90% increase in energy costs.

Energy cost is also strongly dependent upon discount rates used. This is shown in Figure 6-9 for the Southwest region in 1990. For electric power production, an 11% nominal rate was utilized, giving an energy output cost of approximately 80 mills/kWh. However, if industrial discount rates (which are closer to 20% in nominal terms) were utilized, this same solar pond system would have to return about 150 mills/kWh for the pond system to be profitable. In this case, the higher the discount rate, the greater the impact of a percentage increase in the rate. For example, a 50% change from 8 to 12% has less impact on costs than a 50% increase from 12 to 18% would have.

Another factor that was examined was the sensitivity of output costs to the years of construction time. This relationship is illustrated in Figure 6-10. This relationship is shown for the Southwest region in 1990. As indicated in Figure 6-10, construction time has a relatively small impact

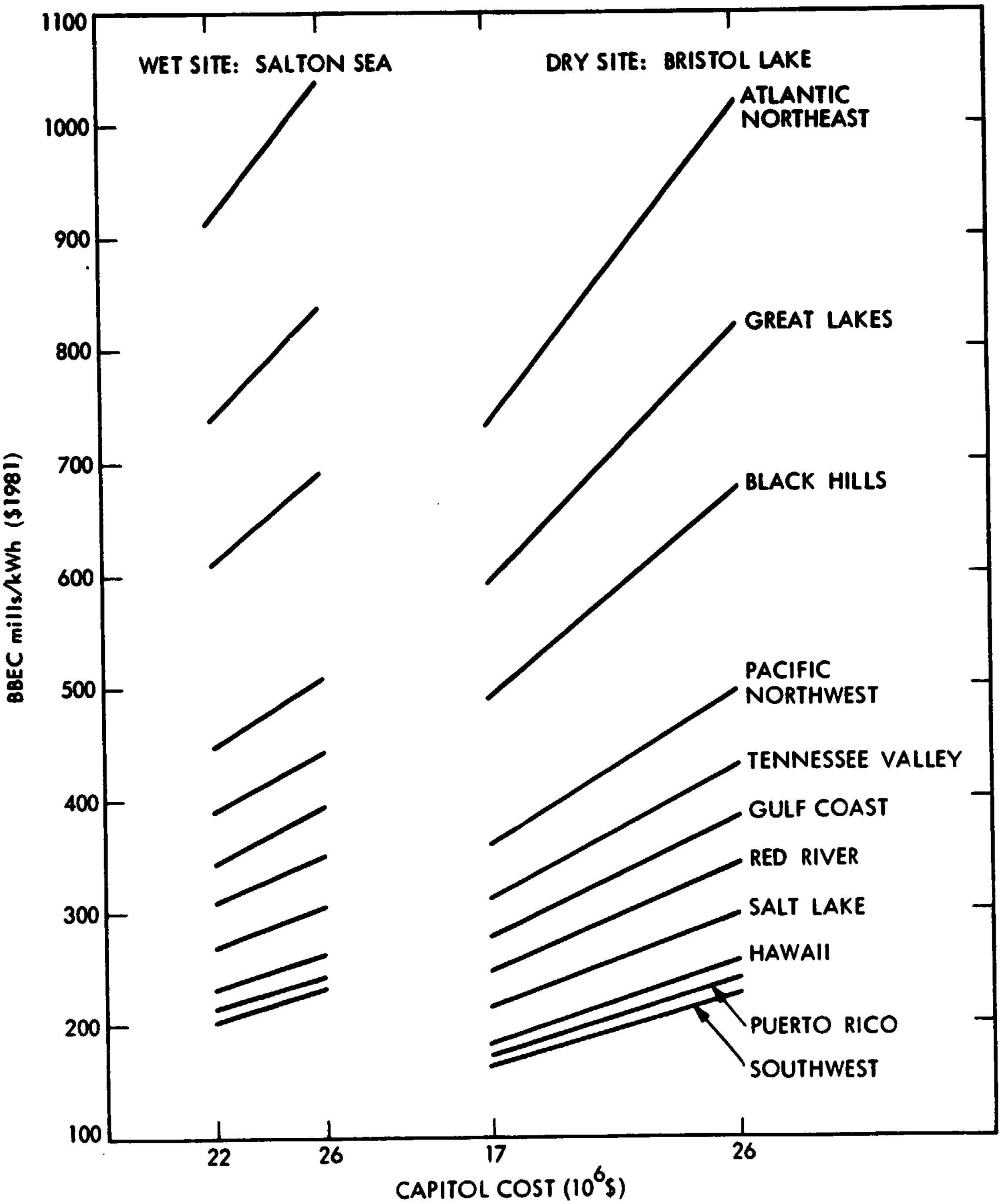


Figure 6-6. Electric Energy Costs from a 5-MW Solar Pond Power Plant: Wet Site and Dry Site Cases

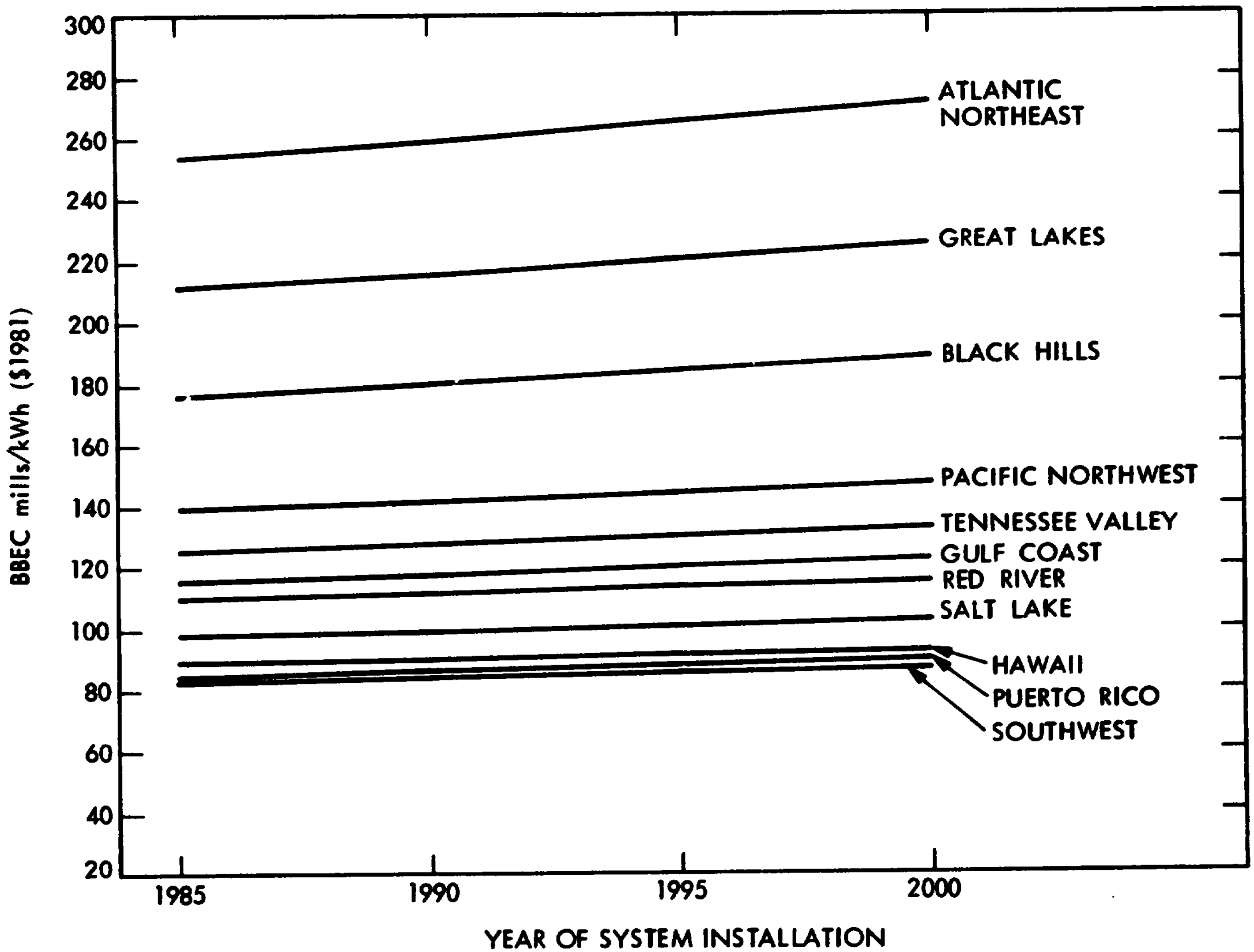


Figure 6-7. Solar Pond Energy Cost Estimates: 600-MW Power Plant at Salton Sea

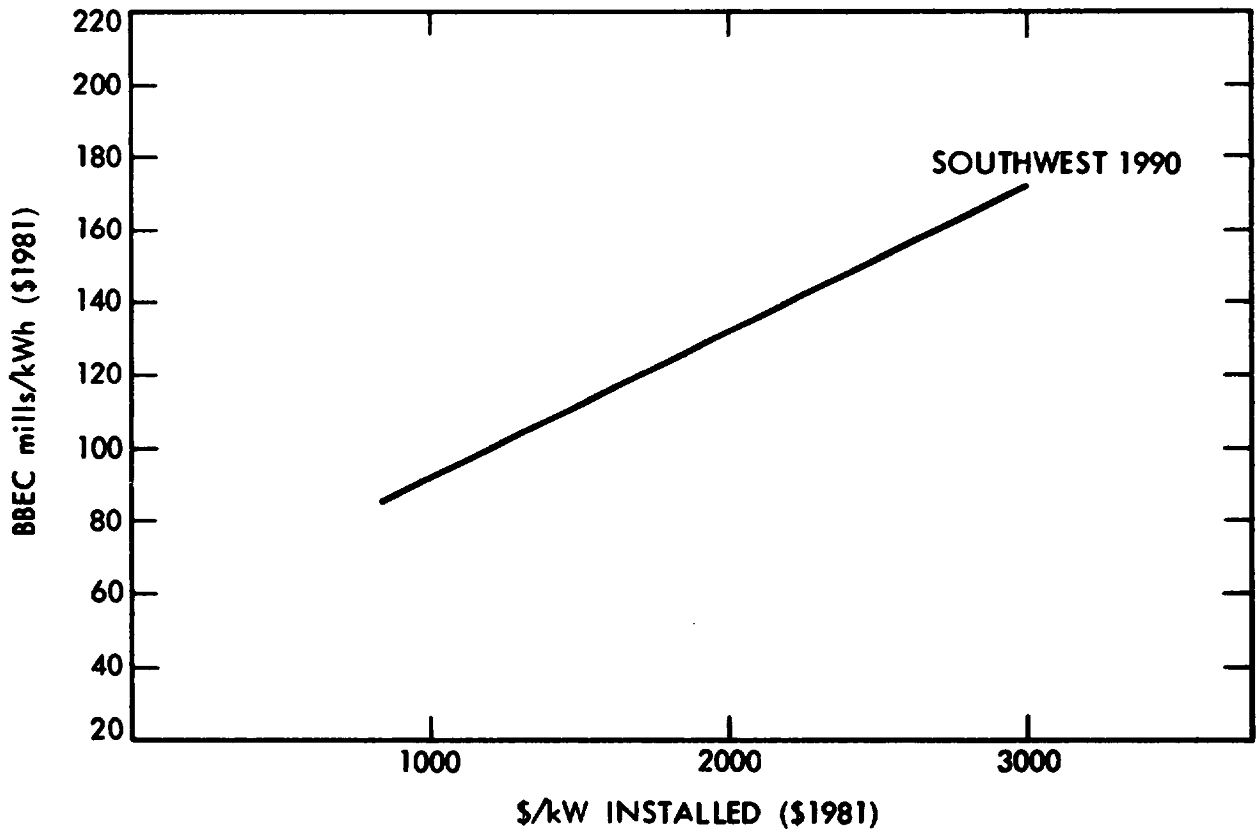


Figure 6-8. Sensitivity of Electricity Costs to Capital Costs

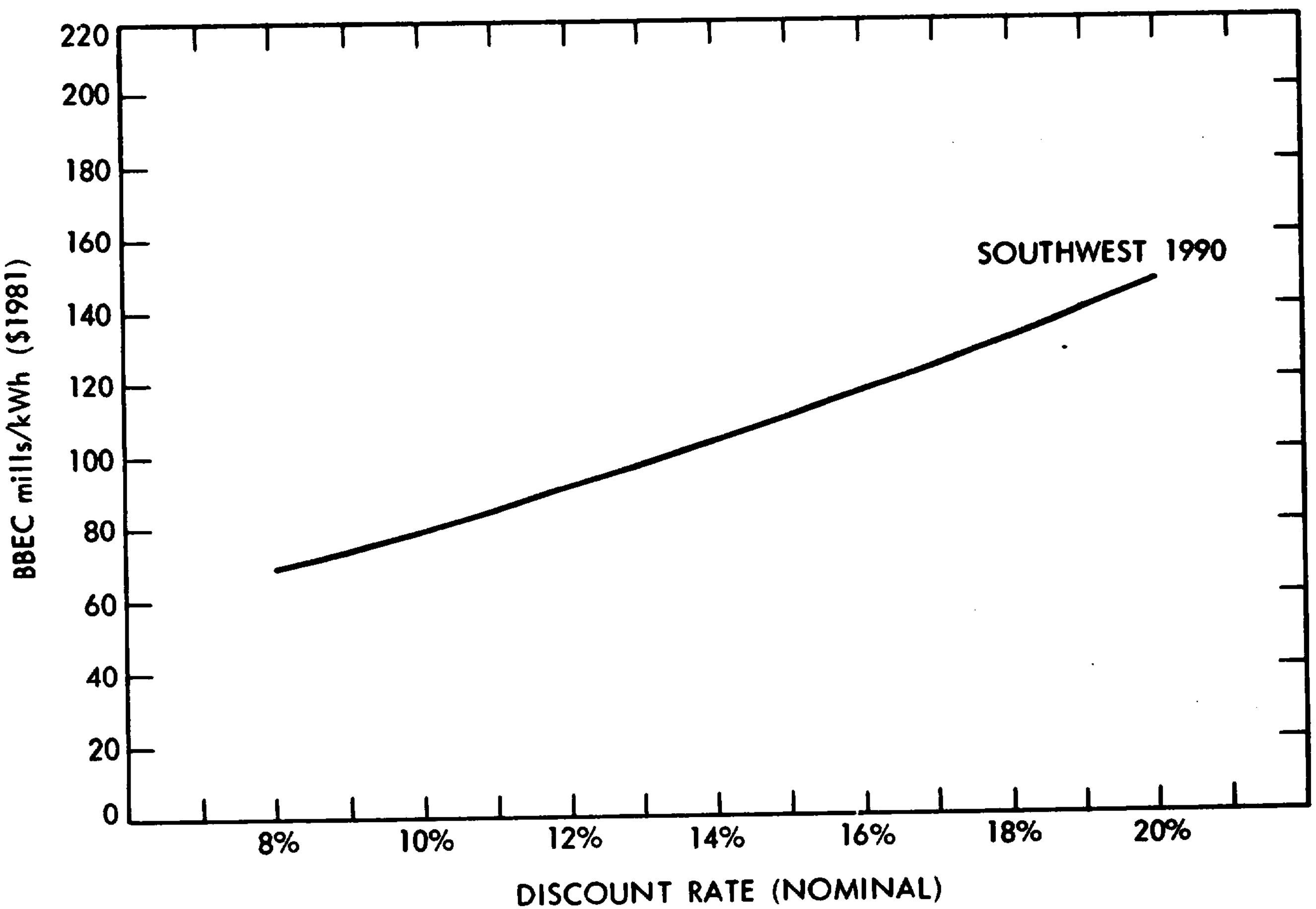


Figure 6-9. Sensitivity of Electricity Costs to Discount Rates

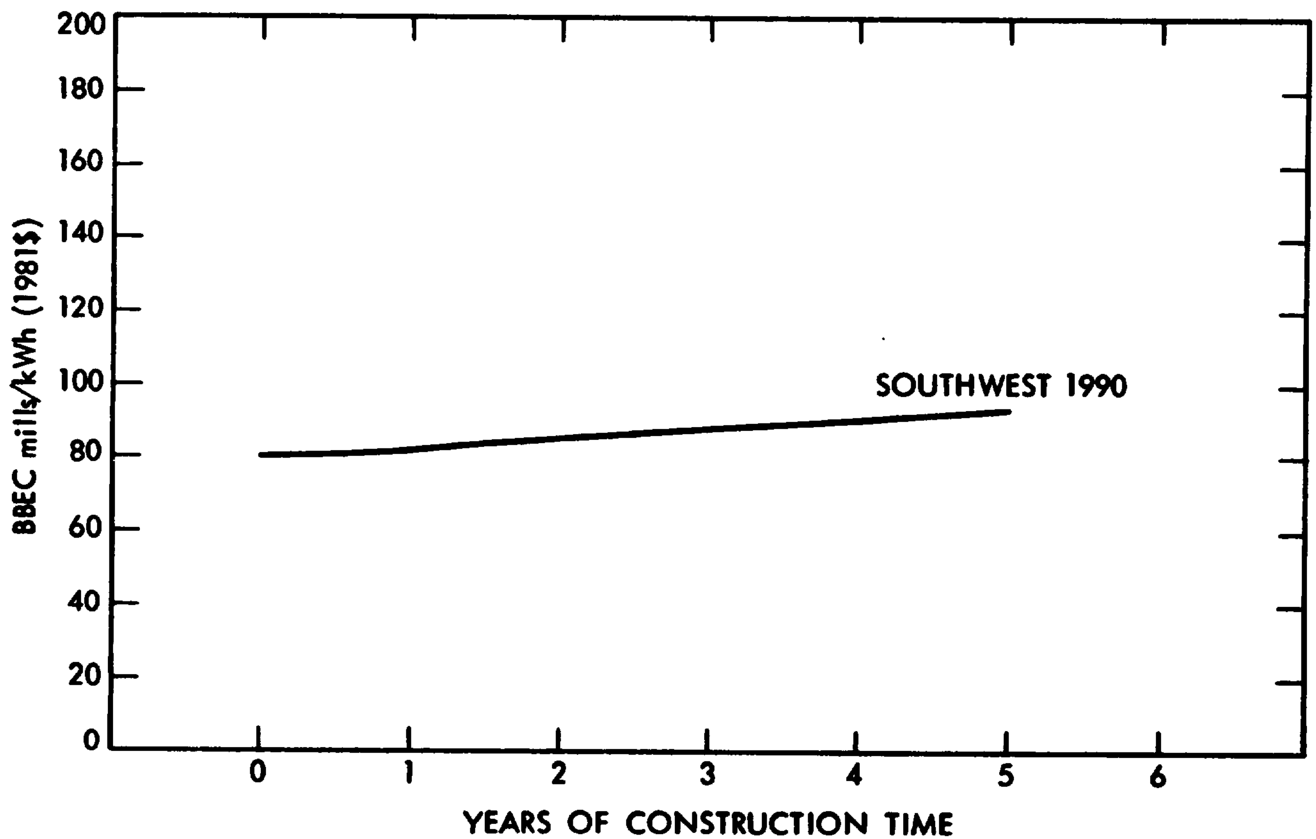


Figure 6-10. Sensitivity of Pond Output Costs to Construction Times

on energy output costs. The difference is due to variations in relative escalation and inflation rates. Thus, the capital cost and discount rate are the most important factors in the final solar pond energy output costs.

6.4 CONVENTIONAL ENERGY COSTS

The energy output costs calculated in Section 6.3 provide little indication as to whether or not solar ponds would be utilized in the various regions. In order to determine whether or not ponds would be utilized, they must be compared with the alternatives that are available. One of the ways that alternatives may be compared is through relative costs. Thus, this section indicates the costs of alternative, conventional energy systems. Although this does not by itself indicate whether or not solar ponds are adopted -- other factors, such as reliability, simplicity, and environmental and institutional concerns will also be important in the decision -- relative costs can provide an initial indication of the desirability of using solar ponds.

Table 6-7 gives the average commercial natural gas prices, obtained from Data Resources, Inc. The price given is the Data Resources' price for the region in which the solar pond representative city is located, translated into 1981 dollars. This price can be compared with the solar pond thermal application cost estimates, with two provisions. First, the effect of deregulation is a major uncertainty in natural gas price estimates; thus, these prices may be low. Second, industrial process heat frequently can be provided by the lowest grade fuel available, in which case the price of natural gas is an unrealistically high comparison.

On the basis of these costs, natural gas is cheaper to utilize than ponds in all regions for industrial applications. If municipal thermal applications are considered, the answer is somewhat different. When 1990 natural gas prices are compared with Figure 6-5, approximately half of the pond capital costs for the least cost regions (Hawaii, Southwest, Puerto Rico) appear viable. The two lower cost cases (3 and 4) also appear cost-effective in the next group of regions (Tennessee Valley, Gulf Coast, Red River, Salt Lake). However, it must be emphasized that this viability depends upon the tax-exempt status and low discount rate requirements of municipalities.

Tables 6-8 through 6-11 give a basis for comparison of electrical generation costs with new coal- and oil-powered plants. These costs were generated as part of a cost comparison analysis for solar thermal parabolic dish applications (Habib-agahi and Smith, 1981). Again, the regional comparisons are made by comparing the study region in which the solar pond representative city is located with the solar pond region.

For electric power applications, the new 8-MW municipal oil-powered plant was more expensive in the Southwest and Hawaii than the 5-MW solar pond under any capital cost and operation and maintenance scenario examined. The 5-MW solar pond would also be competitive with the 8-MW oil-fired plant in the Salt Lake Region and the Red River Region if the pond capital costs and O&M costs can be kept at the lower bounds analyzed (i.e., the lower capital costs for the dry site, Bristol Lake). The dry site, lower bound cost scenario

Table 6-7. Average Commercial Natural Gas Prices[a] ($/MBtu, 1981$)[b]

Solar Pond Region	DRI Region	1985	1990	1995	2000
Southwest	Pacific	5.84	8.17	9.47	9.48
Salt Lake	Mountain-2	4.69	8.04	9.28	9.25
Red River	West South Central	5.08	7.60	8.88	8.93
Northwest	Pacific	5.84	8.17	9.47	9.48
Black Hills	West North Central	4.69	8.09	9.46	9.46
Great Lakes	East North Central	5.10	8.26	9.58	9.58
Tennessee Valley	East South Central-1	4.61	8.40	9.65	9.62
Gulf Coast	South Atlantic	5.43	8.85	10.16	10.12
Atlantic Northeast	Middle Atlantic	6.11	9.33	10.67	10.60
Alaska	Pacific	5.84	8.17	9.47	9.48
Hawaii	Pacific	5.84	8.17	9.47	9.48
Puerto Rico	None				

[a]Source: Data Resources, Inc., 1981.
[b]The DRI prices in ¢/therm are converted to 1981 $/MBtu. Prices are for the DRI region in which the representative city lies.

would also place a solar pond close to competitive (4% difference) with an 8-MW oil plant in the Gulf Coast Region, and in the Tennessee Valley Region (11% difference). The 5-MW solar pond does not appear to be cost-competitive with any size coal power plant.

A 600-MW solar pond installed in the Southwest Region, the Red River Region, or Hawaii will be competitive with any of the three sizes of coal power plants installed in those regions. Solar ponds installed in the Black Hills, Great Lakes, Atlantic Northeast and Alaska do not appear to be cost-competitive with any coal power plants examined. All other regions have some conditions under which they seem to be competitive. In the Salt Lake Region, pond costs compare favorably with a 280-MW coal power plant over the entire time period, but with a 500-MW and 1000-MW coal power plant only for 1995 and 2000. In the Pacific Northwest, a large solar pond looks cost-competitive with a 280-MW coal power plant by 1995, but not until 2000 for the two larger coal plants. A large solar pond in the Gulf Coast Region would be cost competitive with a 280-MW and 500-MW coal plant from 1990 on, but not until 1995

Table 6-8. Levelized Busbar Energy Costs: New Municipal Coal Power Plants[a] (1000 MW, 1981$ mills/kWh)

Solar Pond Region	Corresponding Study Region	1985	1990	1995	2000
Southwest	Pacific	89	108	130	156
Salt Lake	Mountain-2	74	89	107	129
Red River	West South Central-2	97	118	144	176
Pacific Northwest	Pacific	89	108	130	156
Black Hills	West North Central	67	76	87	98
Great Lakes	East North Central	98	112	128	145
Tennessee Valley	East South Central-1	86	97	110	124
Gulf Coast	South Atlantic	101	116	133	154
Atlantic Northeast	Middle Atlantic	92	105	120	137
Alaska	Pacific	89	108	130	156
Hawaii	Pacific	89	108	130	156
Puerto Rico	None				

[a]Source: Habib-agahi, H., and Smith, J. H., January 1981.

for the 1000-MW coal plant, as the economies of scale bring down cost of the coal plants. Finally, a 600-MW solar pond in the Tennessee Valley region is barely competitive, only appearing competitive in the year 2000 with a 280-MW coal plant.

The data sources used contained no alternative energy costs for Puerto Rico. If we assume, however, that costs in Puerto Rico would be comparable to costs in Hawaii, then solar ponds would have very favorable cost comparisons. Land availability could be a problem with Puerto Rico, but if a pond could be constructed along the sea coast, it may be feasible. The government of Puerto Rico has great flexibility in the tax status it grants industries considered to be desirable or healthy for the Puerto Rican economy. The pond costs could be brought down further by different tax treatments.

6.5 COMPARISON OF SOLAR POND AND CONVENTIONAL ENERGY COSTS

When the solar pond energy costs that have been developed in Section 6.3 are compared with the costs of the conventional energy described in Section 6.4, the following key points may be made:

Table 6-9. Levelized Busbar Energy Costs: New Municipal Coal Power Plants[a] (500 MW, 1981$ mills/kWh)

Solar Pond Region	Corresponding Study Region	1985	1990	1995	2000
Southwest	Pacific	95	111	133	161
Salt Lake	Mountain-2	76	91	110	133
Red River	West South Central-2	99	120	146	179
Pacific Northwest	Pacific	92	111	133	161
Black Hills	West North Central	70	79	90	102
Great Lakes	East North Central	100	115	130	150
Tennessee Valley	East South Central-1	88	100	112	128
Gulf Coast	South Atlantic	102	118	137	157
Atlantic Northeast	Middle Atlantic	95	108	122	140
Alaska	Pacific	92	111	133	161
Hawaii	Pacific	92	111	133	161
Puerto Rico	None				

[a]Source: Habib-agahi, H., and Smith, J. H., 1981.

(1) When thermal industrial applications are examined, and solar ponds are compared with natural gas, no solar ponds are viable in any region in the 1980-2000 time period within the construction cost range considered. Except for thermal municipal applications, a subset of pond capital costs and regions appear to be viable after 1990.

(2) When the 250-acre electric power production solar pond is compared with a small (8-MW) new oil-fired facility:

(a) Solar ponds in the Southwest, Hawaii, and Puerto Rico regions are viable within the capital cost range considered.

(b) If capital costs are held in the lower half (less than $\$50/m^2$) of the capital cost range, ponds are also competitive in the Salt Lake and Red River regions, and are close to oil-powered costs for the Gulf Coast and Tennessee Valley regions.

Table 6-10. Levelized Busbar Energy Costs: New Municipal Coal Power Plant[a] (280 MW, 1981$ mills/kWh)

Solar Pond Region	Corresponding Study Region	1985	1990	1995	2000
Southwest	Pacific	113	137	165	198
Salt Lake	Mountain-2	98	117	141	170
Red River	West South Central-2	116	141	172	209
Pacific Northwest	Pacific	113	137	165	198
Black Hills	West North Central	86	97	110	126
Great Lakes	East North Central	106	121	139	159
Tennessee Valley	East South Central-1	95	108	122	139
Gulf Coast	South Atlantic	112	130	150	173
Atlantic Northeast	Middle Atlantic	106	120	138	157
Alaska	Pacific	113	137	165	198
Hawaii	Pacific	113	137	165	198
Puerto Rico	None				

[a]Source: Habib-agahi, H., and Smith, J. H., 1981.

(3) When a 250-acre pond for electric power production is compared with any type of electric power production from coal, the solar pond is not competitive.

(4) When a 26,400-acre pond is compared with coal:

(a) Solar ponds are competitive with a wide variety of coal plants in the Southwest, Red River, and Hawaii regions for the range of pond capital costs considered.

(b) Solar ponds are not competitive in the Black Hills, Great Lakes, Atlantic Northeast, and Alaska.

(c) In all other regions, solar ponds can be competitive under specific time horizons, capital cost assumptions, and assumptions about the available alternatives.

Table 6-11. Levelized Busbar Energy Costs -- New Municipal Oil Power Plant[a] (8 MW, 1981$ mills/kWh)

Solar Pond Region	Corresponding Study Region	1985	1990	1995	2000
Southwest Region	Pacific	265	323	391	476
Salt Lake Region	Mountain-2	207	252	307	375
Red River Region	West South Central-2	204	247	299	363
Pacific Northwest Region	Pacific	265	323	391	476
Black Hills Region	West North Central	174	205	239	281
Great Lakes Region	East North Central	265	323	391	476
Tennessee Valley Region	East South Central-1	219	266	325	396
Gulf Coast Region	South Atlantic	219	266	325	396
Atlantic Northeast Region	Middle Atlantic	227	275	334	405
Alaska	Pacific	265	323	391	476
Hawaii	Pacific	265	323	391	476
Puerto Rico	None				

[a]Source: Habib-agahi, H., and Smith, J. H., 1981.

(5) The estimated energy costs from solar ponds are not very dependent upon year of installation, or assumptions about the length of the construction period.

(6) Energy costs are strongly dependent upon insolation levels, the discount rate, and initial capital cost.

It is important to determine which factors were most important to these results, and which characteristics have minimal impact upon solar pond energy costs. The key factors in the results presented in Section 6.3 were the following:

(1) Insolation levels. This is the most important factor in relative regional costs; tax rate differentials (the only other difference in regional solar pond costs) were negligible. As shown in Table 6-2, the energy output that might be expected in thermal and electric power production applications varied dramatically. For example, two identical

26,400-acre ponds would have different electric power production capacities, depending upon whether they were in Madison (the Great Lakes region), with a capacity of 90 MW, or if the pond was located in Daggett, California Southwest region), with a capacity of 332 MW. This large difference in energy output capacity will have significant impacts upon energy cost over the assumed 20-year lifetime of the pond.

(2) Discount rate. Because the discount rate minimizes the value of revenues and energy savings which occur far into the future, higher discount rates will tend to make investments with high initial capital costs (such as solar ponds) but continuous energy savings look less attractive than investments which are evaluated at lower discount rates. Part of the reason that no industrial thermal application appears feasible is that industrial thermal applications were evaluated with a 20% nominal discount rate, while utility applications were evaluated with an 11% nominal rate. The difference in discount rates is due to the fact that utilities may float tax-free bonds, and therefore can obtain funds at a lower rate. This lower discount rate for electric power applications will tend to make more regions, time periods, and capital costs of solar ponds viable. How- ever, this difference in discount rates is used in other sources as well; it is consistent with the rates used by Data Resources, Inc. and the Solar Thermal Program at the Jet Propulsion Laboratory.

(3) Capital costs. Because the majority of costs associated with solar ponds must be incurred before the pond is operational, these capital costs contribute significantly to the energy output costs of ponds. When a pond is an expensive prototype rather than a commercial design, when extensive construction and diking must be undertaken, or when salts must be purchased rather than utilized from existing brines, these factors will have a significant impact upon capital costs, and therefore upon busbar energy costs.

This section has compared the relative costs of energy from solar ponds with the costs of energy from alternatives in two applications (thermal and electric) for 12 regions. Depending on the alternative energy sources that are available, solar ponds are competitive in a variety of electric power production and certain thermal applications. This assessment of relative energy costs has not considered other potential advantages of solar ponds. For example, some industries may be able to develop solar ponds from existing brine evaporation ponds or waste water ponds. In these cases, the initial costs of developing the pond will be minimal, and the pond may control either salinity or toxic waste while producing energy. Such dual-use ponds would be useful on both environmental and financial grounds.

SECTION 7

ASSESSMENTS OF SOLAR POND APPLICABILITY AND POTENTIAL IN THE UNITED STATES

7.1 REGIONAL APPLICABILITY

The applicability of solar ponds to the various regions and market sectors is determined by:

(1) Need for low-temperature thermal energy (less than 200°F) or electric power.

(2) Availability of the necessary resources.

(3) Suitability of the pertinent physical conditions.

(4) Economic viability (at least long-term) of pond energy.

(5) Satisfaction of other constraints (e.g., environmental and institutional).

These criteria are obvious, as ponds will not be built if energy needs do not exist, resources are not available, climatic or hydrogeologic conditions are not suitable, or long-term economic viability is not achievable. (In this context, long-term means by the year 2000, and near-term means within the next 5 years.)

The essential natural resources were evaluated and pertinent physical conditions examined in Section 2. The regional need for low-temperature thermal energy (less than 200°F) or electric power was surveyed by market sectors in Section 5. The economics of pond energy was assessed on the basis of current and projected financial conditions in Section 6. Other constraints, such as environmental, institutional, social, political, and psychological, are mostly site-specific, and hence, are not considered in this regional assessment. This section utilizes the results of these surveys and analyses to determine the regional applicability of solar ponds by market sectors.

As emphasized throughout this report, applicability within a region is a gross assessment. It should not be interpreted to mean that a pond can be built on every site within the region. Nor should it be interpreted to mean that no ponds will be built in regions indicated as not applicable. The gross assessment is the result of a series of screening processes, to be refined by more detailed investigation for district-specific or site-specific purposes.

7.2 ENERGY SUPPLY POTENTIAL

Energy supply potential of solar ponds by the year 2000 is estimated by region and by market sector in the following sections. Understandably,

"future potential" can be defined, estimated, and interpreted in various ways. Factors considered here include the market needs for thermal or electric energy, the availability of resources, the predicted regional performance of solar ponds, the long-term economic viability of pond energy, and future market expansion.

However, uncertainty about these factors exists and estimates vary widely. For example, past or current data on market energy demand contain uncertainties of their own, and assumptions such as excluding solar pond preheating use in the IPH sector may only be partially valid. Although the survey extensively examined pond resources, some have been omitted and, hence, the survey may be incomplete. The pond performance predictions were based on a set of assumptions, some of which may require further refinement. The postulated financial conditions on which the economic analyses were based, although closely scrutinized and believed to be realistic, may undergo dramatic change in times to come. Future expansion of each individual market may not follow the past trend or the assumptions made here. Finally, the extent to which solar ponds can penetrate the market depends on a host of critical issues, and their future status is not amenable to accurate forecast. Such uncertainties are bound to affect any estimates of future potential. Therefore, care in interpreting these estimates is strongly urged.

7.2.1 Expansion Factor

In the absence of better information, the increasing trend of total national energy consumption will be utilized to estimate expansion factors for energy needs in the IPH and buildings sectors. Several projections exist for the total U.S. energy consumption for the year 2000, as shown in Table 7-1. Such projections differ in accordance with the methods used. Figure 7-1 shows another set of three projections resulting from the Ford Foundation Energy Policy Project, along with explanations of the methods used: historical growth, technical fix and "zero growth." The technical-fix result was used in this report for two reasons. First the chief assumption, that a conscious national effort in energy conservation will occur, appears realistic. Second, the technical-fix result agrees closely with most of the projections listed in Table 7-1. Thus, the total national energy consumption in the year 2000 is hypothesized to be 124 quads.

The IPH market survey (Section 5.2) utilized a 1976 data base, and the total national energy consumption in 1976 was 74.5 quads. Because the industrial energy growth follows approximately the national energy growth (Dorf, 1981), an expansion factor of 124/74.5 = 1.66 will be applied to the 1976 IPH energy requirement data.

The APH market survey (Section 5.3) utilized a 1974 data base. However, agricultural activities in the U.S. appear to have been declining. For example, total U.S. farm land decreased from 1,202 x 10^6 acres in 1950 to 1,072 x 10^6 acres in 1977; total U.S. farm population decreased from 30.5 million in 1940 to 7.8 million in 1977; and total U.S. annual farm energy expenditure decreased from $1.86 billion in 1965 to $1.74 billion in 1973, both in constant 1958 dollars, (Dorf, 1981). Assuming that a continued

Table 7-1. Projections for the Year 2000 for the Total Energy Consumption in the United States[a]

Investigator	Consumption (10^{15} Btu)
1. National Energy Plan (1977)[a]	125
2. Electric Power Research Institute (1979)[b]	130
3. Earl T. Hayes (1979)[c]	95
4. von Hippel/Lovins (1977)[d]	89-95
5. U.S. Dept. of Energy (1979)[e]	125

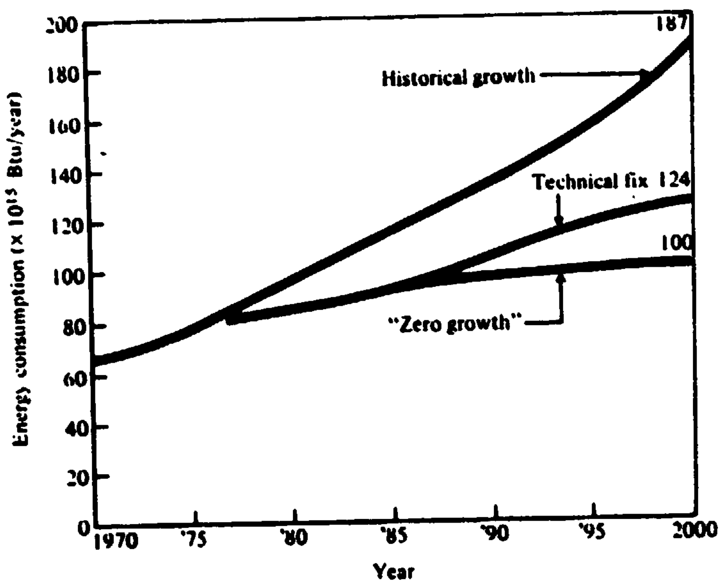
[a]Source: U.S. Department of Energy.
[b]Source: EPRI Journal, May 1979.
[c]Source: E.T. Hayes, Science, January 19, 1979, pg. 234.
[d]Source: Power Engineering, May 1979, pg. 25.
[e]Source: U.S. Department of Energy, Energy Information Administration, April 1979.

decline does not occur, at least not to a significant extent, an expansion factor of 1.0 (i.e., no expansion) will be applied to the 1974 APH energy requirement data as presented in Section 5.3.

The breakdown by state of energy consumption in the residential, commercial and institutional buildings sector was presented in Table 5-4. These data show that the total national energy consumption for 1979 was 79 quads. Because the annual growth rate for household and commercial energy consumption has been reduced to 2% since 1973 from the previous 7% (Section 5.1), an expansion factor of $(1.02)^{20} = 1.49$ will be applied to the 1979 data base to project the year-2000 consumption in the buildings sector.

7.2.2 Market Penetration

How many solar ponds will actually be built by the year 2000? This question depends on many critical issues, including emphasis of the Federal Government, federal and local political climate, local institutional and environmental regulations, the state of the economy, the financial environment, prices of fossil fuels, development of each market sector, the willingness of private sectors to participate in solar-pond commercialization, etc. For example, the growing interest of private sectors has been evident recently. However, the initial market development will be slow, unless the Federal Government can provide the incentives needed by the private sectors, or at least strongly support several significant prototype pond projects that clearly demonstrate the viability and attractiveness of solar ponds. Research and Development efforts directed specifically to reducing pond costs, in addition to understanding pond phenomena, will also help. However, the evolution of these critical issues during the next 2 decades is unpredictable.



Three forecasts of energy consumption in the United States during the period 1975 to 2000, resulting from the Ford Foundation Energy Policy Project. The first forecast is based on the assumption that energy use in the United States will continue to grow until the end of the century at about 3.4% annually, the average rate of growth from 1950 to 1970. The second forecast, based on the assumption that a conscious national effort to use energy more efficiently through the introduction of energy-conserving technology, is called the technical fix scenario. The Ford Foundation project finally proposes a zero energy growth scenario. While called zero growth, it actually has decreasing growth rates eventually reaching zero after 2000. The scenario assumes a growth rate of 1.76% from 1975 to 1985 and 0.47% over the period 1985 to 2000. (Source: The Ford Foundation, 1974.)

Figure 7-1. United States National Energy Consumption (10^{15} Btu/year)

Consequently, it is believed that any assumption on market penetration will not be meaningful. An alternative approach is therefore taken which leaves open the question of market penetration. Readers will have the opportunity to assign their own fractional market penetration numbers, if necessary. This is reflected in the following definition of pond potential.

7.2.3 Definition of Solar Pond Energy Supply Potential

In view of the above discussions, solar pond potential is defined as the energy-producing capacity of solar ponds that can, but has not yet, and will not necessarily, become a reality. This potential will be estimated for the year 2000 by considering the availability of resources, the extent to which these resources can reasonably be exploited, the projected need for thermal or electrical energy by the various market sectors, the technical factors pertinent to design and performance of solar ponds, and the long-term economic viability of solar pond energy. This potential will be expressed in the number of quads of energy producible by solar ponds, or the number of acres of solar ponds that can come into being, given suitable conditions over the next 2 decades. However, this potential will not represent, and should not be interpreted as representing, the amount of energy that solar ponds will be producing by the year 2000.

7.3 RESIDENTIAL, COMMERCIAL AND INSTITUTIONAL BUILDINGS SECTOR

7.3.1 Applicability

With the exception of Alaska, U.S. solar ponds can provide thermal energy at sufficiently high temperature for building space heating and domestic water heating in all regions. Because a low insolation and low ambient temperatures in Alaska, solar ponds located there could not produce thermal energy at temperatures higher than 45°C unless they were equipped with reflectors to enhance solar collection. As discussed previously, space cooling using solar ponds is feasible in principle but requires further research and development to improve its performance.

The need for thermal energy in space heating/cooling and domestic water heating exists in every state and region. Generally, building heating loads decrease from north to south, whereas the converse is true for cooling loads. Water heating loads tend to be uniform throughout all regions. In the north, deeper ponds are required to store thermal energy collected in the summer for use in space heating during the winter. In the south, shallower ponds will suffice as winter heating load is light and summer cooling load peaks in phase with insolation.

From heat-loss considerations, a very small pond serving an average-size single-family dwelling is not practical. A pond of one-half to several acres serving a group of single-family houses, a multi-family dwelling complex, a sizable commercial or institutional building, or a district composed of a large number of various types of buildings is more appropriate. At this size, salt and water requirements are moderate, and imported salts are a viable option for many locations. Therefore, salts and water availability should generally not be a severely limiting factor.

The availability of low-cost land in proximity to the end-use buildings will be a limiting factor, however, because in most developed areas vacant land is scarce and costly. For this reason, a greater number of ponds are expected in currently undeveloped areas for which ponds can be readily incorporated during the planning and design phases. The number of ponds retrofitted in the developed areas is expected to be relatively small.

The economics of solar ponds for thermal applications was investigated in Section 6. Although space and water heating load characteristics for buildings differ from the base case considered in Section 6 (less so for air conditioning), the results of Section 6 constitute a meaningful indication of pond energy economics in the residential, commercial and institutional buildings sector. Insolation level, pond capital cost and discount rate are the three most critical factors that affect the competitiveness of ponds. As shown in Figures 6-5 and 6-7, the higher the insolation level in a region, the more favorable the economics. Since the pond capital cost varies with site, and the discount rate changes with time and financing arrangements, only a broad overview of economic feasibility is appropriate for the regional assessment. If a discount rate of 11% is applicable, then thermal energy from ponds for building heating/cooling and water heating applications will be competitive with most conventional fuels in the Southwest, Puerto Rico, and Hawaii regions, and in the remaining regions if capital costs are sufficiently low (Fig. 6-5). However, if a discount rate of 20% is appropriate, then ponds will be economically competitive in most high and moderate insolation regions only if very low capital costs are also attainable.

The regions where solar ponds are applicable for buildings uses are shown in Figure 7-2. Those regions where current or near-term economic feasibility is possible are also indicated. Figure 7-2 represents only a general indication appropriate for the regional assessment. Isolated sites possessing special conditions can always become exceptions.

7.3.2 Potential

The potential of solar ponds to supply thermal energy for space heating/cooling and domestic water heating in the residential, commercial and institutional (RCI) buildings sector is not need limited, but rather resource constrained. In particular, it is limited by the availability of low-cost land, which is required for pond construction. The Benham Group's land study has estimated the pond-suitable land acreage in both the developed and undeveloped buildings sectors. The pond potential estimation (described in Section 5.1.4) has considered only the undeveloped land (as determined by the local zoning ordinances) and has further reduced the land availability estimates of the Benham Group. The added conservatism was intended to account for other possible land usage that may develop in time, and for the likely occurence that certain housing development patterns may not be suitable for solar pond incorporation.

Regional pond potential estimates based on land constraint and predicted pond performance were presented in Table 5-10 and shown in Figure 7-2. The total U.S. pond potential in the RCI buildings sector is 3.27 quads/yr, which amounts to less than 12% of the projected year-2000 energy needs for

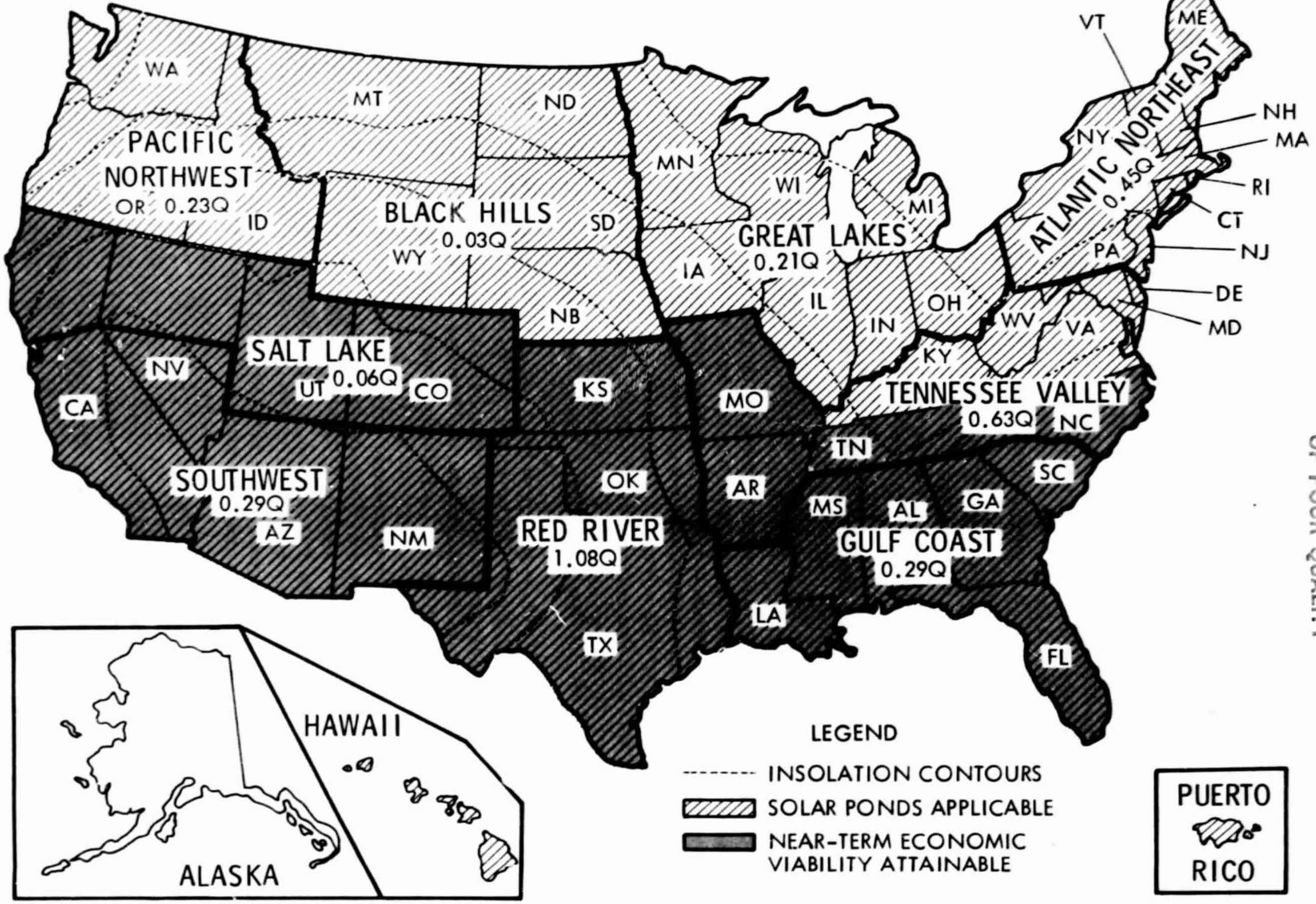


Figure 7-2. Regional Applicability and Potential of Solar Pond Residential, Commercial and Institutional Buildings Applications (3.27 quads/yr)

space heating/cooling and water heating. The Red River region leads others with a potential of 1.08 quads/yr because it has the largest pond-suitable-land acreage and relatively high pond performance. Although the Great Lakes region has the greatest thermal energy needs (almost 2.5 times those of the Red River region), it possesses only a modest quantity of pond-suitable land, and pond energy output in that region is relatively low. Consequently, pond potential for the Great Lakes region is low. Future development progress may not follow the ranking of potential as estimated now, however. The northern-heating and southern-cooling emphases and differential readiness of ponds for heating and cooling are bound to affect the course of pond development in the RCI buildings sector.

7.4 INDUSTRIAL PROCESS HEAT SECTOR

7.4.1 Applicability

As discussed in Section 5.2, need for thermal energy below 200°F within the manufacturing sector (SIC Code Categories 20-39) is concentrated in the states of California and Washington, most of the Red River, Gulf Coast and Atlantic Northeast regions, part of the Tennessee Valley region, and all of the Great Lakes region; see Table 5-13. Details on the types of industrial process requiring low-temperature thermal energy within these regions are presented in Section 5.2. Food, furniture, paper, chemicals, leather, stone/clay/glass and primary metals processing are among the major consumers to which solar pond energy can be suitable. The use of solar ponds for preheating in some higher-temperature processes was not considered in this study, since appropriate conservation measures such as waste heat utilization might be more readily and economically implemented.

The majority of solar ponds in the industrial sector will not be very large. Hence, salts and water resources are not expected to be as limiting as land. Land limitation will likely result in fewer ponds constructed in SMSAs than in non-SMSAs. Many of the more than 176,000 existing impoundments may well be suitable for conversion into solar ponds.

Based on the results of economic analyses as presented in Section 6 (Fig. 6-3 and 6-5), near-term economic viability is expected in California, and most of Red River and Gulf Coast regions (Fig. 7.3). Early application of solar ponds are more probable in the food processing and chemical industries. Within the Great Lakes, Tennessee Valley and Atlantic Northeast regions, near-term economic viability will be achieved only if low capital costs and favorable financial conditions can be obtained.

7.4.2 Potential

Assuming that all of the manufacturing thermal energy needs in the non-SMSAs (less than 200°F), and only half of those in the SMSAs are to be met by solar ponds, industrial pond potential was estimated using the 1976 data base as given in Table 5-17 of Section 5.2. The expansion factor of 1.66 was then applied to obtain the year 2000 estimate, rationale for the expansion factor was being discussed in Section 7.2. The regional solar pond potentials

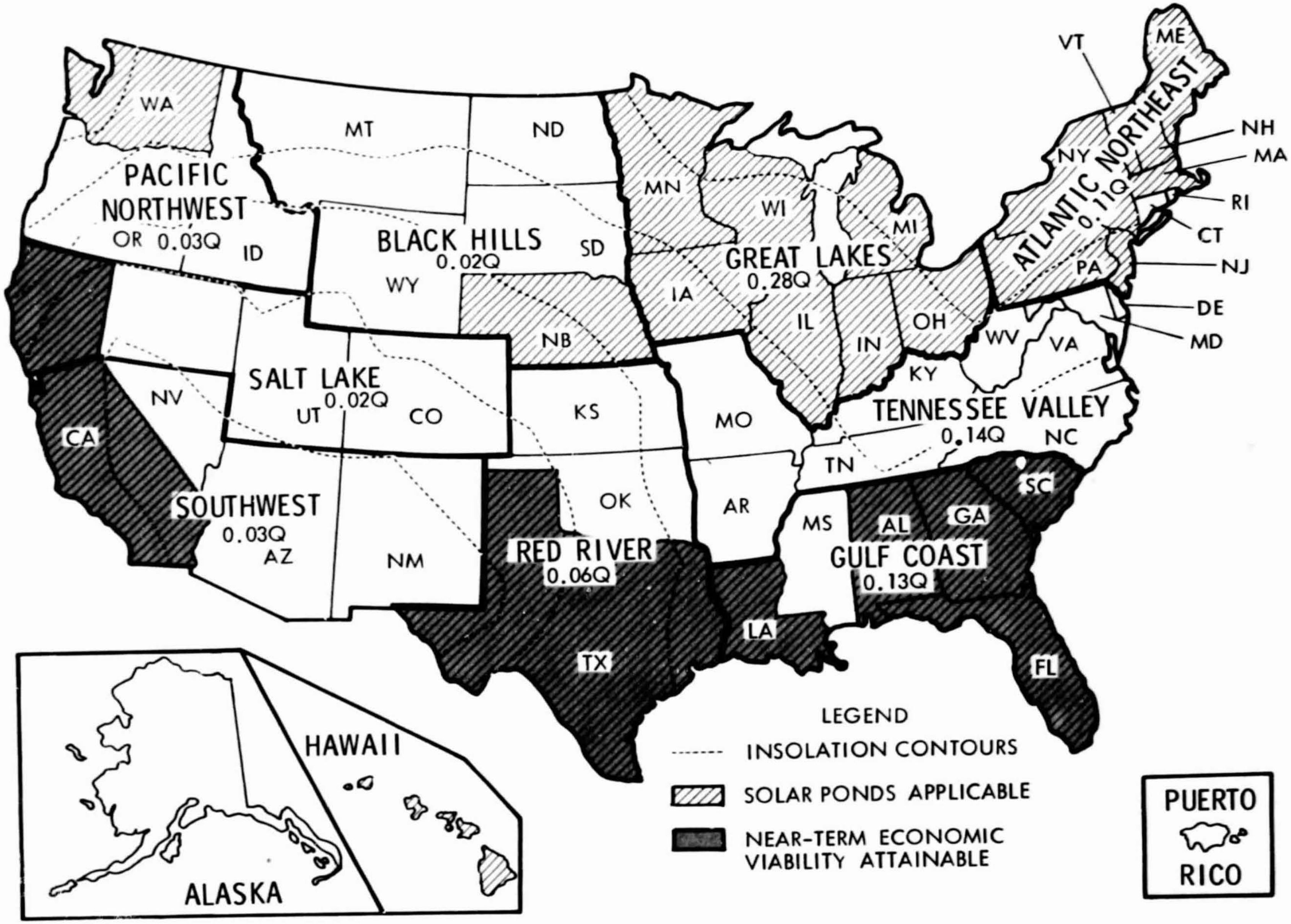


Figure 7-3. Regional Applicability and Potential of Solar Pond Industrial Process Heat Applications (0.82 quads/yr)

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in the industrial sector are thus computed to be: Great Lakes region, 0.28 quads/yr; Tennessee Valley region, 0.14 quads/yr; Gulf Coast region, 0.13 quads/yr; Atlantic Northeast region, 0.11 quads/yr; Red River region, 0.06 quads/yr; Southwest region, 0.03 quads/yr; Pacific Northwest region, 0.03 quads/yr; Salt Lake region, 0.02 quads/yr; and Black Hills region, 0.02 quads/yr. These are indicated in Figure 7-3. The total pond potential for the year 2000 in the industrial sector is thus 0.82 quads/yr. Note that preheating use of solar ponds and non-manufacturing industrial processes such as mining are not included in this estimate. In comparison, Edesses (1980) projected a 0.6 quads/yr potential where he combined the industrial and agricultural sectors and assumed a 30% market penetration. Ochs (1980) estimated a 2.4 quads/yr potential where he included possible contribution of solar ponds in preheating. If preheating were excluded, then the Ochs estimate would be reduced 4- to 5-fold, according to the data that he used.

7.5 AGRICULTURAL PROCESS HEAT SECTOR

7.5.1 Applicability

Agricultural activities occur throughout most of the country. Only a few states are exceptions, having limited agricultural production due to geological or climatic restrictions. Solar ponds can supply thermal energy to a number of agricultural processes: crop drying, livestock brooding, livestock waste disposal, space and water heating for live-stock shelters, greenhouse conditioning, and farmhouse space and water heating. Irrigation pumping also consumes a significant fraction of agricultural energy, and solar ponds should be able to provide electricity or shaft power needed for this purpose.

The regions where solar ponds can be applied are shown in Figure 7.4. The states of Nevada, Montana, Wyoming, North Dakota and those within and neighboring the Atlantic Northeast region are not included in the applicable regions primarily because of their limited needs for agricultural thermal energy. A limited number of isolated solar pond installations within these states are certainly probable. Although the applicable regions appear widespread, more ponds for agricultural uses are expected, based on needs and resource availability, in the Red River, Great Lakes and Southwest regions. As shown in Table 5-20, the Red River region ranks first in agricultural thermal energy need that can be met by solar ponds, followed by the Great Lakes and Southwest regions.

Farm ponds are expected to be moderately sized. A one-acre pond will be able to supply most of the thermal energy needs of a several-hundred-acre farm. Locally occurring salt resources are not crucial. Water demand will not be overly severe. Locating a several-acre pond on a large farm should not constitute a problem. Appropriate pond liner or ground sealer will be required in most cases, however, to guard against possible contamination of productive land.

A multi-purpose farm pond is envisioned as an integral part of a large farm landscapes, built near the farm house, animal shelters, greenhouses, and the crop processing machineries. The high-yield period of a pond (i.e., fall) happens to coincide with the high energy-demand period of most farms as crop processing activities largely occur around this time.

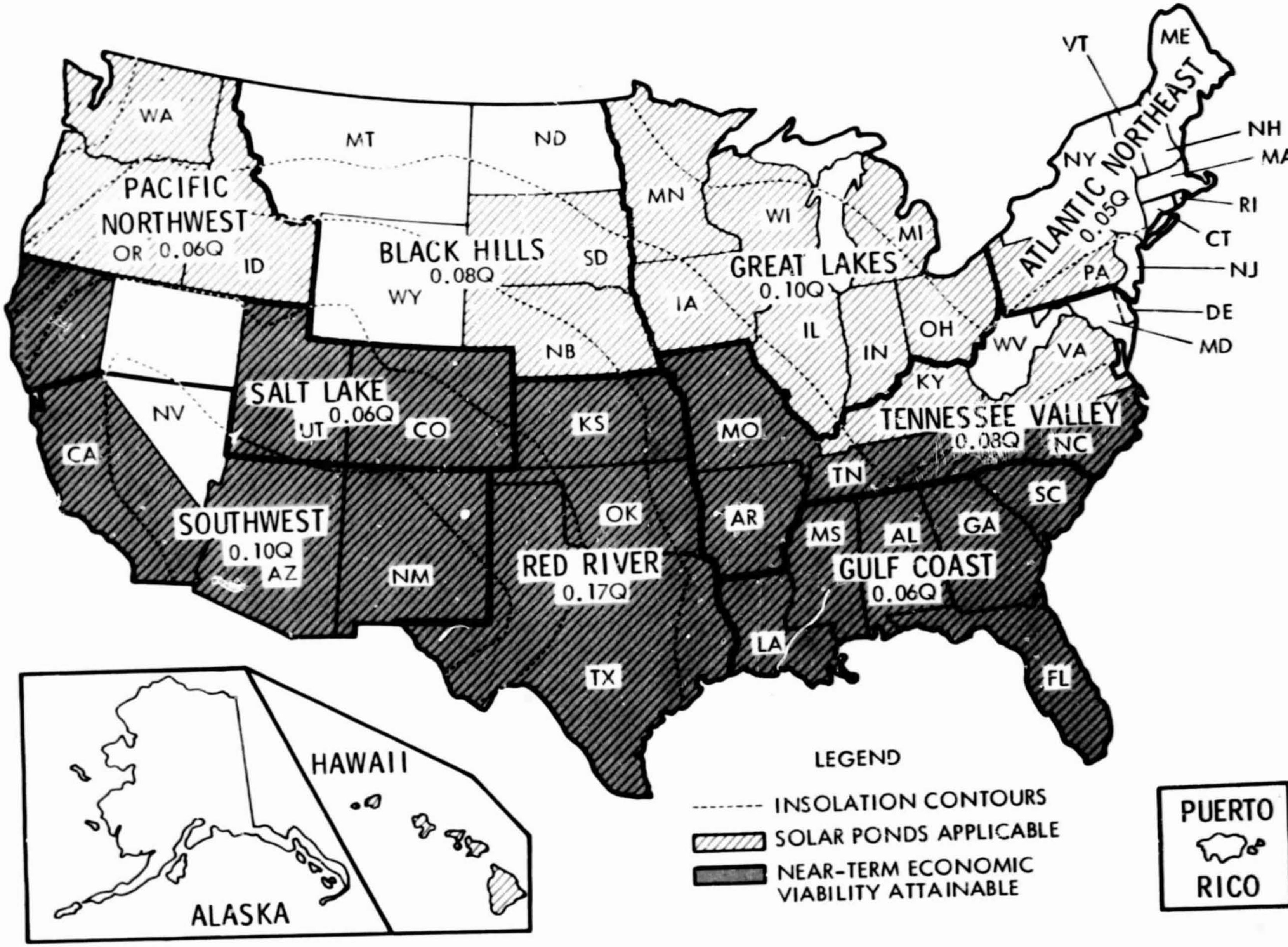

Figure 7-4. Regionl Applicability and Potential of Solar Pond Agricultural Process Heat Applications (0.76 quads/yr)

Near-term economic viability for farm ponds is likely to occur in the higher insolation regions, as indicated in Figure 7-4. This is again based on economic analyses performed for the base case thermal ponds as discussed in Section 6. Although the Great Lakes region has relatively low insolation, it may have sites whose local financial conditions and resource availability are favorable enough to render ponds competitive with alternatives in the near term.

7.5.2 Potential

Information presented in Section 5.3 was largely based on a 1974 data base which contains details suitable for a regional breakdown. However, as observed in Section 7.2, significant expansion of the U.S. agricultural sector is not expected. Therefore, data contained in Table 5-20 will be used as a basis for estimation of agricultural pond potential. In addition, the 0.3 quads/yr energy needs for farm house space and water heating, which was discussed in Section 5.3.2.5 but not included in Table 5-20, will be added to the total. Thus the solar pond potential for supplying thermal energy to the agricultural sector is estimated for the various regions as follows: Red River region, 0.17 quads/yr; Southwest region, 0.10 quads/yr; Great Lakes region, 0.10 quads/yr; Black Hills region, 0.08 quads/yr; Tennessee Valley region, 0.08 quads/yr; Gulf Coast region, 0.06 quads/yr; Salt Lake region, 0.06 quads/yr; Pacific Northwest region, 0.06 quads/yr; and Atlantic Northeast region, 0.05 quads/yr. These are shown in Figure 7-4, along with the sum total of 0.76 quads/yr for the entire United States.

7.6 ELECTRIC POWER SECTOR

7.6.1 Applicability

Solar pond application in the electric power sector is perceived to be limited by resources rather than need. Most of the United States is or can become connected to utility grids, and the grids presumably can absorb any amount of power that is generated by solar ponds.

Electric-power-generating solar ponds will be mostly large-scale, tens or hundreds or thousands of acres in area, constructed on sites where the essential natural resources (sunshine, land, salts and water) are available at low or no cost. Many of these sites will likely be situated away from population centers. The design, construction, operation and maintenance of these ponds will be significantly different from those of thermal ponds. The physical, economical, environmental, and other factors that affect the installation and performance of these ponds will also be considered in a different light than thermal ponds. Smaller ponds built to generate electricity for specific community use or industrial plant applications can also be expected, but the various technical and economic considerations for these may deviate from the large-scale ponds. Existing impoundments may receive attention for conversion into solar ponds power plants.

The evaluation of natural resources presented in Section 2, particularly in connection with water and salts/brine, has provided insight

for siting of potential electricity-generating ponds. The applicable regions are shown in Figure 7-5, where specific potential sites are also indicated. A list of specific potential pond sites for electric power generation was given in Table 3-34. More detailed discussion on these sites or regions can be found in Section 5.4.

According to the economic analyses reported in Section 6, for a commercial-size solar pond power plant (600 MWe), present or near-term economic viability is attainable in the Southwest, Puerto Rico, Hawaii, Salt Lake, Red River, and Gulf Coast regions. This is also indicated in Figure 7-5. For a smaller plant, on the order of 5 MWe for example, the per kilowatt installed capital cost will be increased, and regions where pond power is economically competitive with alternatives will be restricted.

7.6.2 Potential

Detailed assessments of resources in the primary solar-pond siting states were presented in Section 5.4.2, along with estimates of electric power generating potential. Somewhat arbitrary but conservative assumptions on utilization of these resources were made in the estimation. The regional electric power generating potential of solar ponds in the year 2000 are: Red River region, 2.03 quads/yr; Gulf Coast region, 0.63 quads/yr; Salt Lake region, 0.55 quads/yr; Southwest region, 0.25 quads/yr; this gives a sum total of 3.46 quads/yr. The regional potentials are indicated in Figure 7-5. Note that these include only the large-scale solar pond power plants. Small-scale electricity-generating ponds such as may be employed in the industrial sector have not been included in this estimate.

7.7 DESALINATION SECTOR

7.7.1 Applicability

The current desalination market for solar ponds is small, but need for desalination is projected to increase substantially during the next 2 decades. As discussed in Section 2.1.3, most of the country west of about 96 degrees longitude has been water-deficient. Population and economic growth continue to demand more and more water from local and regional supplies. Energy development is expected to put significant additional strain on the existing water resources. In addition, salinity levels in certain major water streams are increasing and water pollution is becoming more of a problem in most regions. As a consequence, the demand on desalted water has been projected to grow from 273 mgd as of 1981 to 2500 mgd in the year 2000. (Note that this Arthur D. Little projection is more than an order of magnitude lower than an independent Flour Co. projection.)

Solar ponds are perceived to be capable of providing thermal energy to the distillation desalination process, and electric or mechanical power to the reverse osmosis and electrodialysis processes. To date, limited studies have been performed on this particular application, and further R&D efforts need to be conducted.

Solar ponds for desalting purposes may be located near population centers, in which case land and other resource constraints must be satisfied,

C-4

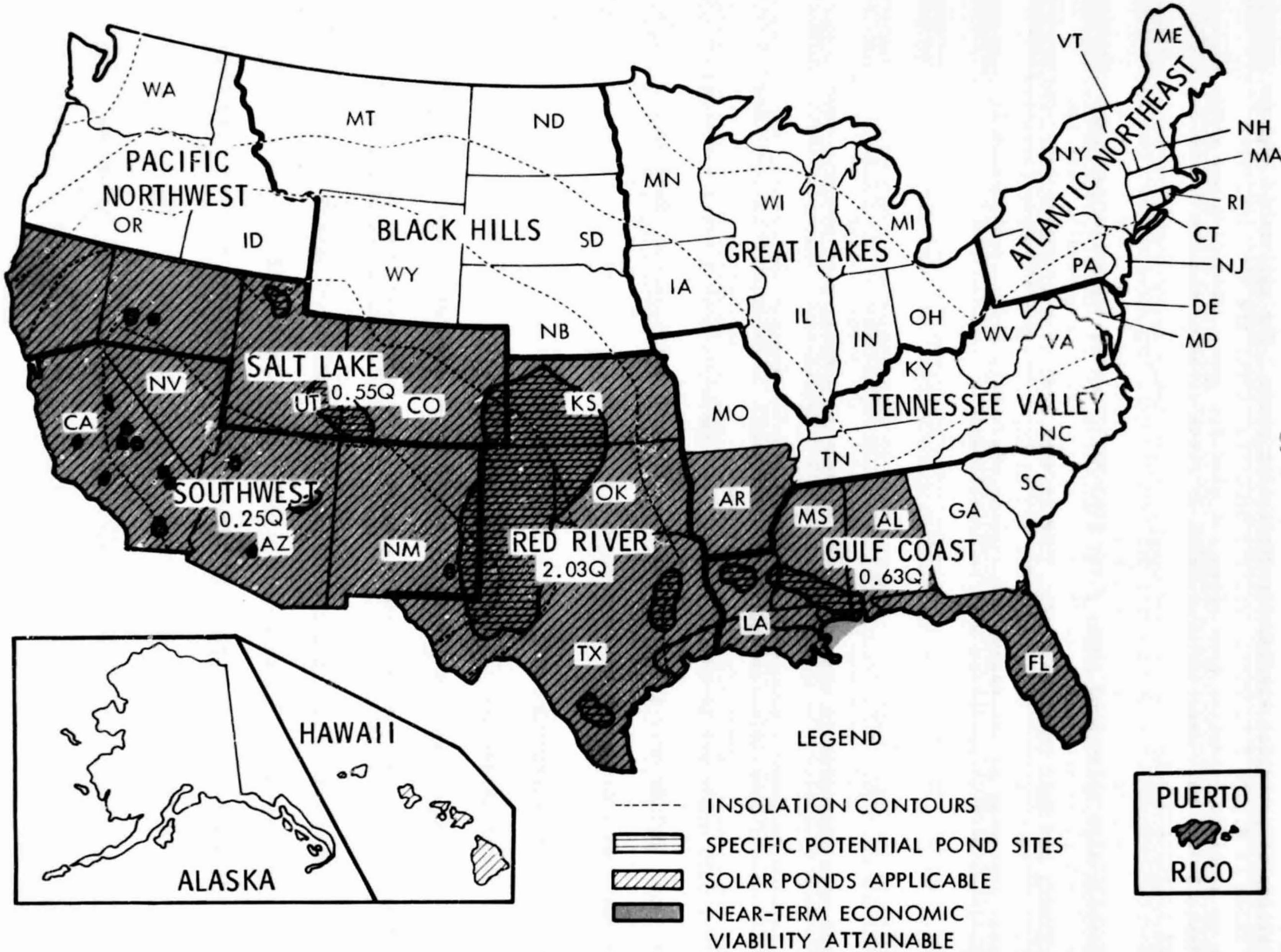

Figure 7-5. Regional Applicability and Potential of Solar Pond Electric Power Generation (3.46 quads/yr)

or in remote areas where the requisite resources may be abundant. As discussed in Section 5.5, a number of options is available for integrating solar ponds into desalinat processes. An advantage that has been pointed out is that while solar p provide thermal, mechanical or electric energy to desalination processes, the desalting plant effluent can be utilized by ponds, resulting in cost reduction both in effluent disposal for the plant and brine concentration for the pond.

Regions that have been projected to require sustantial desalting by the year 2000 (Section 5.5) and where solar ponds can be applied are the Southwest, Salt Lake, Red River, Gulf Coast, and Tennessee Valley. These are shown in Figure 7-6. Since these regions have either high or moderate insolation, economic viability appears to be achievable as indicated in Figure 7-6, based on economic analyses reported in Section 6.

7.7.2 Potential

The projected desalted water demand from low salinity feedwater in the year 2000 is 516 mgd. Assuming all demand to be met by reverse osmosis or electrodialysis plants which obtained their electric power from solar ponds, the pond potential will be 0.02 quads/yr. Desalted water demand from high salinity feedwater was projected to be 2003 mgd for the year 2000. If all demand is met by distillation plants which derived their thermal energy from solar ponds, then the pond potential will be 0.61 quads/yr. Clearly, the potential for high salinity feedwater desalting is much greater than that for low-salinity feedwater. This is an area to focus on in future development of solar ponds. Information contained in Tables 5-43 and 5-44 concerning pond potential is summarized in Figure 7-6. As can be seen in this figure, the Southwest region leads with a solar pond desalting potential of 0.26 quads/yr, followed by the Salt Lake region with 0.19 quads/yr and the Red River region with 0.10 quads/yr. Including the Gulf Coast and Tennessee Valley regions, the total projected solar pond energy supply potential for desalination in the year 2000 is estimated to be 0.63 quads/yr.

7.8 SUMMARY

Regional applicability and potential of solar ponds in the various market sectors as discussed in the foregoing sections are summarized in Table 7-2. Alaska is the only region that is not suitable for operating solar ponds because of its low level of insolation. Ponds are applicable in all the other regions for at least two market sectors. Where applicability is not indicated for a particular market in a particular region, the development of ponds may still be possible if exceptionally favorable conditions exist on certain sites. Applicability implies that at least long-term economic viability (by year 2000) can be achieved. Regions where near-term economic viability is attainable were indicated in Figures 7-2 through 7-6.

Costs of delivered energy from solar ponds are also included in Table 7-2. The costs are in 1981 dollars and are for ponds with a 1990 start-up schedule. The start-up date does not affect energy costs significantly. For example, these costs will be reduced by 1.0 to 1.5% if a 1985 start-up date were considered. With respect to the thermal energy costs, the low

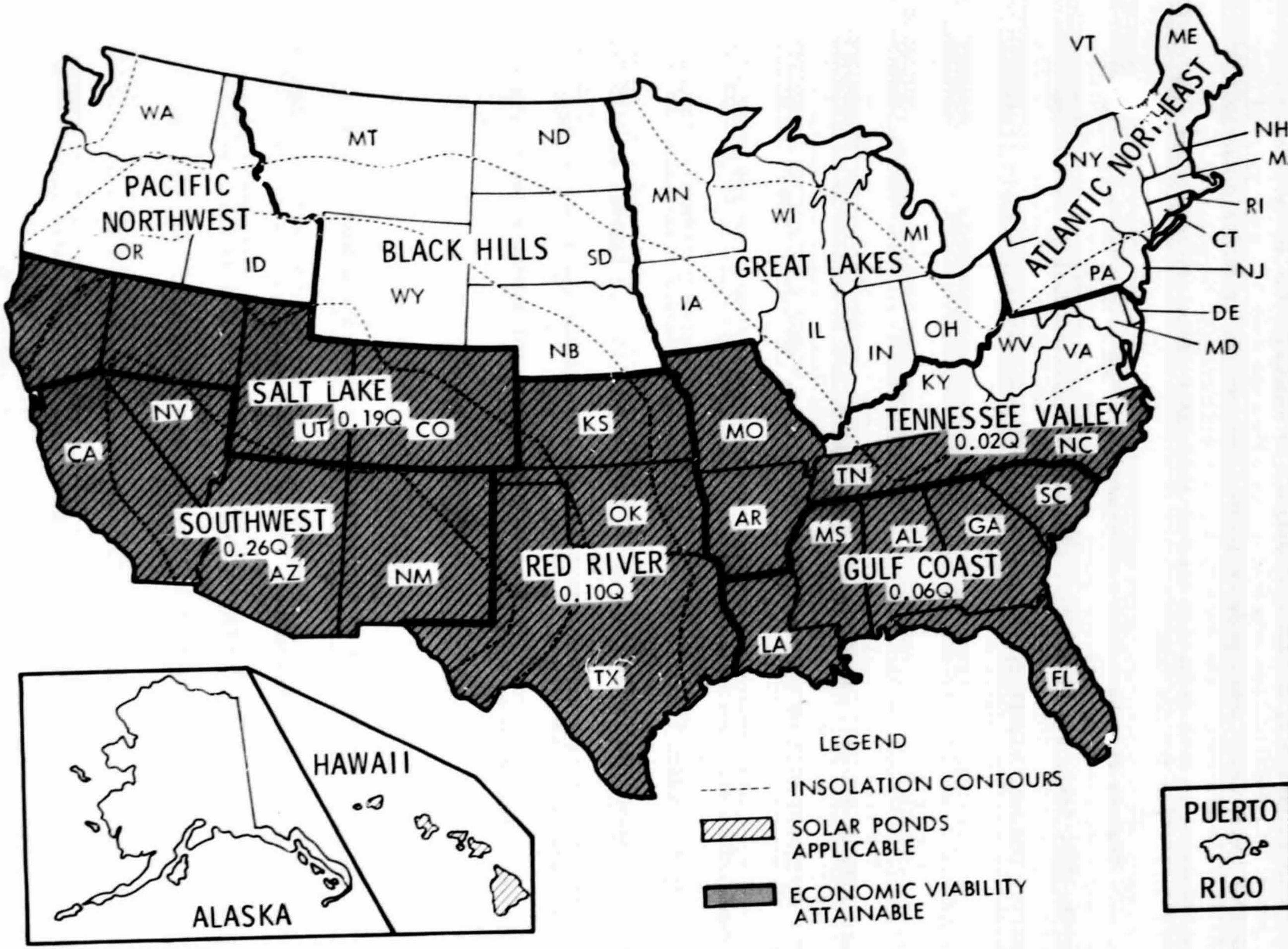

Figure 7-6. Regional Applicability and Potential of Solar Pond Desalination (0.630 quads/yr)

figures in the range are associated with a pond capital cost of $\$31/m^2$ and a discount rate of 11%, while the high figures in the range are associated with a pond capital cost of $\$87/m^2$ and a discount rate of 20%. The busbar electric power costs are based on a discount rate of 11%, with the low figures based on capital cost estimates developed for a 600-MWe commercial-size solar pond power plant at the Salton Sea, and the high figures related to a 5-MWe plant at the same location. The other pertinent financial factors are: inflation rate = 7.2%; O&M escalation rate = 9.3%; capital escalation rate = 7.2%; system lifetime = 20 years; construction time = 2 years; miscellaneous expense rate = 2.25%; investment tax credit rate = 10%; depreciation by the sum-of-years-digits method; and the various local tax rates as appropriate for the regions (which range between 44 and 51%).

When solar ponds are compared with natural gas, for industrial thermal applications (using a discount rate of 20%), no solar ponds will be competitive in any region during the next 2 decades within the capital cost range considered. But for municipal thermal applications (using a discount rate of 11%), ponds will be competitive for a subset of capital costs and regions after 1990. This comparison will of course have to be reexamined if deregulation of natural gas prices takes place.

When a 250-acre solar pond power plant (producing 600 MWe nominal in the Southwest region) is compared with a small (8 MW) new oil-fired facility, the solar pond power plant is competitive in the Southwest, Hawaii and Puerto Rico regions within the capital cost range considered. If the capital costs can be held below $\$50/m^2$, then ponds are also competitive in the Salt Lake and Red River regions, and nearly competitive in the Gulf Coast and Tennessee Valley regions.

When a 26,400-acre pond (producing 600 MWe nominal in the Southwest region) is compared with a coal-fired power plant, the pond is competitive in the Southwest, Red River and Hawaii regions and not competitive in the Black Hills, Great Lakes, Atlantic Northeast and Alaska regions. In all other regions, the solar pond power plant can be competitive under specific time horizons and capital cost ranges. In general, under proper technical and financial conditions, solar ponds can attain near-term economic viability, particularly in the southern high-isolation regions. This is as expected, since higher solar intake results in higher pond energy yield and, hence, lower energy cost.

The energy supply potentials of solar ponds in the year 2000 are also tabulated in Table 7-2 by region and by market sector. Insufficient data are available to enable estimation for the Hawaii and Puerto Rico regions. These regions are small and the quad numbers will be small, but high pond performance and the apparent availability of resources in these regions are expected to make ponds significant energy suppliers to meet the local needs. The Red River region ranks the highest in pond potential, 3.44 quads/yr, for a combination of reasons: abundant resources, strong energy demand, relatively high insolation, and suitable climatic and hydrogeological conditions. The Gulf Coast and Southwest rank second and third, respectively; both have very favorable conditions to support solar pond development. Situated in the Sun Belt, both regions have experienced and will continue to experience healthy economic expansion. Most of this country's first commercial solar pond facilities can be expected in the Red River, Gulf Coast and Southwest regions.

Table 7-2. Regional Applicability and Potential of Salt-Gradient Solar Ponds in the United States

Region	Applicability[a] Market Sector Bldg.	IPH	APH	Elect.	Desal.	Delivered Energy Cost[b] Thermal[c] Energy $/MBtu	Electric[d] Energy ¢/kWh	Energy Supply Potential, quads/yr (year 2000) Market Sector Bldg.	IPH	APH	Elect.	Desal.	Regional Sum	Rank	Total Pond Area, 10^3 acre
Pacific Northwest	x	xx	x			11.7-38.3	14.1- 50.9	0.23	0.03	0.06			0.32	8	82.9
Salt Lake	x	xx	xx	x	x	8.0-25.9	10.0- 30.4	0.06	0.02	0.06	0.55	0.19	0.88	4	706.2
Southwest	x	xx	xx	x	x	6.0-19.5	8.5- 23.5	0.29	0.03	0.10	0.25	0.26	0.93	3	307.5
Black Hills	x	xx	xx			14.7-46.3	18.0- 69.0	0.03	0.02	0.08			0.13	9	42.5
Red River	x	xx	x	x	x	8.3-26.6	11.2- 34.8	1.08	0.06	0.17	2.03	0.10	3.44	1	1301.5
Great Lakes	x	x	x			16.7-54.7	21.5- 83.9	0.21	0.28	0.10			0.59	7	218.5
Tennessee Valley	x	xx	xx	xx	x	9.7-31.3	12.8- 44.0	0.63	0.14	0.08		0.02	0.87	5	186.3
Gulf Coast	x	xx	x	xx	x	9.0-28.7	11.8- 39.1	0.29	0.13	0.06	0.63	0.06	1.17	2	1057.8
Atlantic Northeast	x	xx	xx			18.5-61.9	25.9-104.0	0.45	0.11	0.05			0.61	6	252.1
Alaska	e	e	e	e	e										
Hawaii	x		x	x		6.6-21.0	9.0- 26.2	f	f	f	f	f	f	f	f
Puerto Rico	x			x		6.5-19.5	8.7- 24.5	f	f	f	f	f	f	f	f
United States	x	x	x	x	x			3.27	0.82	0.76	3.46	0.63	8.94		4155.3

[a]The symbol x indicates that solar ponds are applicable in the entire region; xx indicates applicability in parts of the region; and a blank indicates that, disregarding the exceptional cases, solar ponds are not applicable in the region.

[b]Compared with the costs of energy from conventional sources such as natural gas, coal-fired and oil-fired power plants, the costs of energy delivered from solar ponds are generally competitive in the high insolation regions and under reasonable technical and financial conditions. Detailed comparisons are presented in the text of the report.

[c]Energy costs are for a 1990 pond start-up and are in 1981 dollars. The cost range covers a capital cost range of from $31/m² to $87/m² and a discount rate variation from 11% to 20%. Inflation rate = 7.2%. Capital escalation rate = 7.2%. O&M escalation rate = 9.3%. Investment tax credit rate = 10%. Sum-of-years-digits depreciation.

[d]Busbar electricity costs are for a 1990 pond start-up and are in 1981 dollars. The lower figures are based on capital cost estimates developed for a 600-MWe solar pond power plant at the Salton Sea. The higher figures are based on capital cost estimates developed for a 5-MWe plant at the same location. Discount rate = 11%. Other financial parameters are the same as above.

[e]Solar pond not feasible.

[f]Data insufficient for estimation.

The Salt Lake region ranks fourth, with a significant contribution from the Great Salt Lake, whose electric power generating potential tops the nation's inland water bodies. The Tennessee Valley ranks fifth, with favorable conditions for ponds in almost every market sector. The Atlantic Northeast region follows in the ranking, primarily because of a large potential in the residential, commercial and institutional buildings sector. This is so because the region is highly developed, and the pond-suitable land acreage in the to-be-developed areas is second only to that for the Red River region. However, considering the low insolation level and cold winters prevailing in the region and the region's slower economic growth patterns, additional engineering and economic considerations will be required to materialize this potential in the buildings sector. The Great Lakes region ranks seventh; although the agricultural and industrial activities are rather brisk in comparison with other regions, the relatively low insolation level renders application of solar ponds in the other market sectors less attractive. The Pacific Northwest and Black Hills regions are two of the least attractive regions for solar ponds. The explanation lies in low insolation, unfavorable climatic and geological conditions, meager pond resources, and low energy demand.

The total energy supply potential of solar ponds for the United States in the year 2000 is 8.94 quads/yr. This amounts to 7.2% of the projected national energy demand for that year. An estimated 4 million acres of solar ponds will be required to produce 8.94 quads/yr. This total pond area is slightly less than four times the area of the Great Salt Lake, a small quantity compared to the vast expanse of the country.

SECTION 8

CONCLUSIONS AND RECOMMENDATIONS

Abundant resources exist in the United States for the development of salt-gradient solar ponds to supply electric power and low-temperature thermal energy. Climatic and hydrogeological conditions are suitable for operating solar ponds in most regions of the country. Five major market sectors display energy demand characteristics that are compatible with solar ponds. Near-term economic viability is attainable for the pond technology in several regions and markets. The energy supply potential of solar ponds in the year 2000 is estimated at 8.94 quads per year.

These conclusions have been reached through an extensive survey lasting more than a year, and through subsequent data-gathering, computer-modeling, analysis, and evaluation. A regional-assessment approach has been taken to allow for a comprehensive coverage of the entire United States, the major potential market sectors, and the various key technical and economic factors.

The facts and analyses presented in this report are intended to; (1) ascertain the applicability and potential of the emerging solar pond technology, (2) provide input data to the decision-makers on the federal, local and private-sector levels to encourage them to make choices or establish priorities/strategies to advance and commercialize the technology, and (3) provide pond investigators, practitioners and users with an adequate data base to facilitate their future work.

The following conclusions and recommendations have resulted from this study:

(1) Solar ponds are technically and economically viable energy producers that can and should be exploited in the applicable regions and markets of the United States. The potential is high, and actions should be taken on the federal, local and private-sector levels to develop and materialize this potential.

(2) In the initial commercialization stage, the Federal Government should play an active role in providing the local government and private sectors with adequate incentives to stimulate deployment of solar ponds. Co-funding prototype pond projects, and strongly supporting large-scale field experiments and important R&D activities are examples of recommended federal involvements.

(3) Local government and private sector users are the direct beneficiaries, and should take positive steps to bring about an early commercialization of solar ponds.

(4) Regions deserving particular attention are the Red River, Gulf Coast, Southwest and Salt Lake regions, where the pond potential is the highest, the resources are the most

abundant, and the energy demands are the greatest. Specific sites within these regions are, for example, the Salton Sea, the Great Salt Lake, Permian Basin, the Gulf Coast salt domes, Paradox Basin, Supai Basin, the Red River chloride control zones, Galveston Bay, Owens Valley, San Diego Bay, etc. Other specific potential pond sites are listed in Table 5-34.

(5) The electric power production potential of solar ponds is enormous. At an estimated 3.46 quads/yr, electric power ponds represent about 39% of the national pond potential. The recent Israeli success in generating electricity with ponds and the knowledge of this sizeable U.S. potential should stimulate increased emphasis in this market.

(6) The pond potential for space heating/cooling and water heating in the residential, commercial and institutional buildings sector is also very significant, at an estimated 3.27 quads/yr, about 37% of the total national pond potential. However, unlike the electric power market, the buildings market spreads over the country and concentrated development in a few regions is not possible. Moreover, the requirement for space heating is higher in regions with lower insolation, and air-conditioning using solar ponds in the high-insolation regions remains to be demonstrated. Techniques for enhancing solar collection in the low-insolation regions, such as tilted reflectors, should be explored. This will be of value particularly to the Atlantic Northeast region, where pond potential for building space heating is relatively high.

(7) Collection enhancement techniques should also benefit the Great Lakes region, where the IPH market potential is the highest among all regions. The IPH sector possesses over 176,000 existing impoundments whose possible conversion into solar ponds deserves further investigation. Many non-manufacturing industrial processes, such as mining, should be able to utilize ponds. Also, solar ponds may be practical in providing preheat to some high-temperature industrial processes. These are additional study areas that should be pursued in the future.

(8) Multipurpose farm ponds offer a number of distinct advantages to the agricultural sector. Initial development and commercial effort should concentrate on California, Texas and the Great Lakes region.

(9) The desalination market is at present very small, and the estimate for its future potential here is conservative. The possibility exists that tremendous growth in desalting energy consumption may occur in the next 2 decades. Solar ponds coupled with distillation desalting plants may offer several advantages. Future development in this area can focus on the Southwest, Salt Lake, and Red River regions.

(10) Solar pond-desalting plant coupling is but one example of combined technology. Other possible and perhaps promising combinations are solar ponds with sewage treatment, solar pond with oil shale development, solar ponds with mineral recovery including salt production, solar ponds with ethanol production, etc. In most of these combinations, cost benefits can be reaped by both the solar pond and its counterpart. To date, these concepts have received only limited attention. Their future development may again reside largely in the high-insolation regions.

(11) The economic analysis conducted in this study reveals that the major energy cost drivers are the initial capital cost, pond energy output and discount rate. Doubling the capital cost can increase the pond energy cost by 40 to 70%. Doubling the discount rate can increase the pond energy cost by 33 to 102%. But doubling the pond energy output can decrease the energy cost by about 100%. This points out the importance of siting, enhancement of pond performance, reduction of up-front construction cost, and financing arrangement. Creative financing of solar ponds is an issue that has not been specifically addressed and should receive more attention in the future. The impact of reducing construction cost has long been recognized and continued effort should be made to produce low-cost ponds. Enhancing pond performance has been the stated goal of many research programs but few concrete methods have been established to date. Future efforts should be directed toward these three specific areas if the economic viability of ponds is to be further improved.

(12) Speaking of the economic effect of pond performance alone may be misleading. It is actually the performance of the entire pond system that is translated into pond energy economics. Improving the performance of the pond itself is certainly important, but improving the efficiency of the energy distribution subsystem, the power conversion subsystem, and above all, optimizing the entire system, are of crucial importance as well. Solar pond system optimization has barely been addressed, and adequate attention must be paid to the subject.

(13) For locations that lack certain resources, several R&D items may be important. Evaporation suppressants will aid the water-short regions. Alternate, inexpensive salt will benefit regions with no known salt resources. Enhanced evaporation techniques will improve the likelihood of turning low-saline lakes and coastal regions into solar ponds, and increase the nation's salt resources immensely. Floating ponds will remove the land constraint from many populated coastal cities and make deep existing lakes available for converison into solar ponds. Reflectors

around ponds to enhance solar collection have been mentioned in (6) and (7) above. R&D efforts addressing these items will preserve or enlarge the nation's pond resources, and should not be neglected.

(14) This regional assessment provides comprehensive and broad information and overview on the applicability and potential of solar ponds in the United States. The next level of effort should be on a district level and directed toward formulation of master plans. The Utah assessment by Riley and Batty (1981) performed in support of this study, represents a good example for such. Site-specific studies that must be performed before any pond project actually can be launched are best conducted within the structure of larger-scoped long-term planning and regional development guidelines.

SECTION 9

BIBLIOGRAPHY

ASHRAE Handbook of Fundamentals, 1977.

Ainscough, T.L., "Solar Energy for the Hotel/Motel Industry," Solar Cooling and Heating, Architectural, Engineering, and Legal Aspects, Vol. 1, Proceedings of the Solar Cooling and Heating Forum, Miami Beach, Florida, 13-15 December, 1976.

Barbieri, R.H., et al, Process Heat in California: Applications and Potential for Solar Energy in the Industrial Agricultural & Commercial Sectors, Jet Propulsion Laboratory, JPL Document 78-33, Pasadena, California, 1978.

Battelle Columbus Laboratories, Survey of the Applications of Solar Thermal Energy Systems to Industrial Process Heat, NTIS, Springfield, Virginia 22161, 1977.

Bechtel Corporation, Technical and Economic Assessment of the Prospects for Electrical Power Generation by Use of Solar Ponds, August 1975.

Bender, F.E., et al, Solar Energy Applications in Agriculture Potential, Research Needs and Adoption Strategies, NSF/RA-760021, Agricultural Experimental Station, University of Maryland, January 1976.

The Benham Group, Land Availability and Land Value Assessment for Solar Ponds in the United States, Final Report to JPL, 1982.

Bronicki, L., "The Solar Pond Development Program in Israel," Proceedings, Non-Convecting Solar Pond Workshop, pp. 12-1 to 12-26, July 1980.

Brown, K.C., Applications and Systems Studies for Solar Industrial Process Heat, SERI/TR-351-481, Solar Energy Research Institute, Golden, Colorado, January 1980.

Carpenter, S., et al, Solution Mining at Searles Lake, California: A Unique Use for Solar Ponds, paper presented at the International Solar Energy Society, American Sector's Annual Conference, Philadelphia, Pennsylvania, 1981.

Carr, T.T., Hurricanes Affecting the Texas Gulf Coast, Texas Water Development Board Report 49, June 1967.

Casamajor, A.B., The Impact of Land Use on Solar Industrial Process Heat for the Food Processing Industry, Lawrence Livermore Laboratory, Paper presented at Solar Industrial Process Heat Conference, Houston, Texas, December 1980.

Catalytic, Inc., Desalting Handbook for Planners, Second Edition, prepared for U.S. DOI Office of Water Research and Technology, Document No. OWRT TT/80 3, Philadelphia, Pennsylvania, 1979.

Cinquemani, V., et al, Input Data for Solar Sytems, U.S. Dept. of Commerce report prepared for DOE Division of Solar Technology, Environmental and Resource Assessments Branch, under Interagency Agreement No. E(49-26)-1041, November 1978 (Revised August 1979).

Corcoran, W.P., et al, "Solar Water Heating in the Midwest: An Economic Assessment Based on Measured Performance," J. Energy, Vol. 4, No. 1, January-February 1980.

Council for Agriculture Science and Technology, Potential for Energy Conservation in Agriculture, Report No. 40, 1975.

Data Resources, Inc., Energy Review, Lexington, Mass., p. 171, 1981.

DesChenes, C.D., et al, Multiple Use Solar Heat Collection and Storage System for Grain Drying, Paper No. 76-3514, 1976 ASAE Winter Meeting, Chicago, Illinois, pp. 14-17, 1976.

Dobson, J.E., and Shepherd, A.D., Water Availability in 1985 and 1990, ORNL/TM-6777, pp. 3-29 to 3-52, October 1979.

Dorf, R.C., The Energy Factbook, McGraw-Hill, 1981.

Drumheller, K., et al, Comparison of Solar Pond Concepts for Electrical Power Generation, BNWL-1951, October 1975.

Dvoskin, D., Nichol, K., and Heady, E.O., Energy Use for Irrigation in the Seventeen Western States, Special Report, Center for Agricultural and Rural Development, Iowa State University, Ames, Iowa, July 1975.

Durrenberger, R., and Brazel, A., "Need for a Better Solar Radiation Data Base," Science 19, 1154-5, September 1976.

Eckert, E.R.G., and Drake, R.M., Analysis of Heat and Mass Transfer, McGraw-Hill, 1972.

Edesess, M., "Solar Ponds Resource Potential," Proceedings Non-Convective Solar Pond Workshop, pp. 2-1 to 2-14, July 1980.

Edesess, M., "Solar Ponds Economics, Proceedings, Non-Convective Solar-Pond Workshop, pp. 4-1 to 4-8, July 1980.

El-Ramly, N.A., and Congdon, C.E., Desalting Plants Inventory, Report No. 6. prepared by the National Water Supply Improvement Association, Contract No. 34-0001-7526 for the U.S. DOI Office of Water Research and Technology, 1977.

El-Ramly, N.A., and Congdon, C.F., Desalting Plants Inventory Report No. 7, prepared by the Techno-Economic Services for the National Water Supply Improvement Association, Honolulu, 1981.

Farrington, R.B., et al, A Comparison of Six Generic Solar Domestic Hot Water Systems, SERI/RR-351-413, Solar Energy Research Institute, April 1980.

Finlayson, F.C., Residential Photovoltaic Systems: A Review and Comparative Evaluation of Four Independent Studies of Potential Concepts, SAND80-7010, Sandia National Laboratories, April 1980.

Flour Engineers and Constructors, Inc., Desalting Plans and Progress, An Evaluation of the State-of-the-Art and Future Research and Development Requirements, Second Edition, prepared for the U.S. DOI Office of Water Research and Technology under Contract No. 14-34-0001-7707, Irvine, California, 1978.

Ford Foundation, A Time to Choose: Report of the Energy Policy Project of the Ford Foundation, Ballinger Publishing Co., Cambridge, Massachusetts, 1974.

French, R.L., and Bartera, R.E., Solar Energy for Process Heat: Design Cost Studies of Four Industrial Retrofit Applications, Jet Propulsion Laboratory, JPL Document 78-25, 1978.

General Electric, Solar Heating and Cooling of Buildings, Phase 0, Feasibility and Planning Study, Final Report, NSF-RA-N-74-021C, May 1974.

Geraghty, J.J., Miller, D.W., van der Leeden, and Troise, F.L., Water Atlas of the United States, Water Information Center, May 1973.

Goering, S.W., et al, Residential and Commercial Space Heating and Cooling with Possible Greenhouse Operation; Baca Grande Development, San Luis Valley, Colorado, DOE/ET/28455-3, Coury and Associates, Inc., May 1980.

Habib-agahi, H., and Smith, J. H., Regional Analysis of Solar Thermal Electric and Conventional Power Plants, JPL Internal Document 5105-69, p. 4-4, January 1981.

Hansen, R.W., and Smith, C.C., "Multiple Use Solar Heat Collection and Storage System for Grain Drying," Proceedings, Solar Grain Drying Conference, Urbana-Champaign, Illinois, pp. 11-12, 1977.

Hartzler, R.E., Residential and Commercial Energy Demand, MTR-80W8b, June 1980.

Homer Hoyt Institute, Land Trends, ed. Marhita E. Sumicrast, Washington D.C., 1981.

Hurick, M.G., Solar Electrical Power Generation Pond Potential Sites, Jet Propulsion Laboratory, Internal Document 5030-495, 1981.

Insights West, Solar-Augmented Applications in Industry, Gas Research Institute, Chicago, Illinois 60616, 1980.

Intertechnology Corporation, Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat, NTIS, Springfield, Virginia 22161, 1977.

Ionic, Inc., Bulletin TP-306.

Jackson, J.R., and Johnson, W.S., Commercial Energy Use: A Disaggregation by Fuel, Building Type, and End Use, ORNL/CON-14, Oak Ridge National Laboratory, February 1978.

Jayadev, T.S. and Edesess, M., Solar Ponds, SERI/TR-731-587, Solar Energy Research Institute, Golden, Colorado, 1980.

Jayadev, T.S. and Hendersen, J., Salt Concentration Gradient Solar Ponds - Modeling and Optimization, SERI/TP-35-277, 1977.

Johnson, K.S., and Gonzales, S., Salt Deposits in the United States and Regional Geologic Characteristics Important for Storage of Radioactive Waste, Y/OWI/SUB-7414/1, Earth Resource Associate Inc., Georgia 1978.

M.W. Kellogg Co., Saline Water Conversion Engineering Data Book, prepared for the U.S. DOI Office of Saline Water, New York, 1965.

Ketels, P.A., and Reeve H.R., Market Characterization of Solar Industrial Process Heat Application: Progress Report, Second Quarter 78-79, SERI/PR-353-212, Solar Energy Research Institute, Golden, Colorado, 1979.

Kusuda, T., and Ishii, K., Hourly Solar Radiation Data for Vertical and Horizontal Surfaces on Average Days in the United States, NBS Building Science Series 9b, U.S. Dept. of Commerce, 1977.

Larson and Associates, Desalting Seawater and Brackish Water: Cost Update, 1979, prepared for Oak Ridge National Laboratory, Document No. ORNL/TM-6912, San Diego, 1979.

Latta, A.F., Bowyer, J.M., Fugita, T., and Richter, P.H., The Effects of Regional Insolation Differences Upon Advanced Solar Thermal Electric Power Plant Performance and Energy Costs, DOE/JPL Internal Report 1060-17, Rev. 1, Pasadena, California, 1980.

Lin, E.I.H., Sha, W.T., and Soo, S.L., "Technical and Economic Feasibility of Solar Ponds in Large-Scale Agricultural Applications," Proceedings , 2nd Annual Systems Simulation and Ecomonic Analysis Conference, San Diego, California, January, 1980.

Lin, E.I.H., A Review of the Salt-Gradient Solar Pond Technology, JPL Publication 81-116, DOE.SF-11552-1, January 1982.

Ling, C.S., Waste Water Reclamation Facilities, Survey Report 1978, State of California, Department of Health.

Marsh, H.E., et al, "Salt-Gradient Solar Ponds in the Salton Sea: Brine Optical Quality and Performance," Proceedings of the 16th IECEC, pp. 1720-5, 1981.

Miller, J., "Assessing Residential Land Price Inflation," Urban Land, 1981.

Nielsen, C.E., "Nonconvective Salt Gradient Solar Ponds," Solar Energy Technology Handbook, Chapter 11, pp. 345-375, ed. W.C. Dickinson and P.N., Cheremisinoff, Marcel Dekker, 1980.

Ochs, T., "Solar Ponds as Industrial Process Heat Sources," Proceedings, Non-Convecting Solar Pond Workshop, pp. 8-1 to 8-7, July 1980.

Ormat Turbines, A Study of the Feasibility of a Solar Salt Pond Generating Facility in the State of California, U.S.A., prepared for the Southern California Edison Company under P.O. #M0079003, Israel, 1981.

Ormat Turbines, Ltd., "Determination of Solar Pond Design and Performance Parameters on a Regional Basis", prepared for the Jet Propulsion Laboratory under Contract No. 955975, 1982.

Permasep Permeator, Engineering Design Manual.

Powell, W.R., "Solar/Electric District Heating Via CASES," Proceedings, 15th IECEC, Seattle, Washington, August 18-22, 1980.

Rabl, A., and Nielsen, C.E., "Solar Ponds for Space Heating," Solar Energy, Vol. 17, pp 1-12, 1975.

Rapp, D., "Critique on the Solar Rehabilitation Procedures Used in SOLMET-2," Energy Conversion 19, 101-10, 1979.

Rapp, D., A Critique of the Rehabilitation of Solar Intensity Data from the Old NOAA Network, Final Report on JPL Contract No. 955216, (work sponsored by NASA) Pasadena, California, 1979.

Riley, J.P., and Batty, J.C., The potential for Solar Pond Development in Utah, November 1981.

Rothmerel, T.W., A Planning Model to Project the Potential for Desalting in the United States, prepared by Arthur D. Little, Inc. for the U.S. DOI Office of Saline Water Under Contract No. 14-30-2613, Cambridge, Massachusetts, 1972.

Short, T.H., Roller, W.L., and Badger, P.C., "A Solar Pond for Heating Greenhouses and Rural Residences -- A Preliminary Report," Proceedings "Solar Energy -- Fuel Food" Workshop, Tucson, Arizona, 5-6 April, 1976.

Slonski, M., Energy Systems Economic Analyses (ESEA) Methodology and User's Guide, JPL Document 5101-102, 1979.

Solar Energy Research Institute, "Pre-Design Phase" Section of The Design of Passive Commercial Buildings, to be published by the Solar Energy Research Institute in 1982.

State of Nevada, Department of Conservation and Natural Resources, Division of Environmental Protection, Surface Impoundment Assessment Final Report, 1979.

Styris, D.L., Zaworski, R., Harling, O.K., The Nonconvecting Solar Pond: An Overview of Technological Status and Possible Pond Application, BNWL-1891, January 1975.

Tabor, H., "Solar Ponds," Solar Energy, Vol. 27, pp. 181-194 (1981).

Turner, A.K., Weber, J., and DeAngelis, M., A Geographic Market Suitability Analysis for Low and Intermediate Temperature Solar IPH Systems, Volumes I & II, SERI/TR-733-1194, Solar Energy Research Institute, July 1981.

Ultrasystems, Inc. The Facility Energy Utilization Data System (FEUDS). McLean, Virginia, Undated.

Uniform Building Code, International Conference of Building Officials, 1979.

U.S. Bureau of Census, Annual Survey of Manufacturers, 1976, U.S. Department of Commerce (M74(AS)-4.2 and M74(AS)-2), Washington D.C., 1979.

U.S. Department of Commerce, Environmental Science Services Administration, Environmental Data Service, Climatic Atlas of the United States, Reprinted by the National Oceanic and Atmospheric Association, 1979.

U.S. Department of Commerce, U.S. Census of Housing, 1970; Detailed Housing Characteristics, Final Report HC(1)-B-1, Washington D.C., 1972.

U.S. Department of Energy, Assistant Secretary of Conservation and Renewable Resources, Office of Industrial Programs, The Industrial Energy Efficiency Improvement Program, Annual Report to the Congress and the President, 1979, 1980.

U.S. Department of Energy, End-Use Energy Consumption Data Base: Series 1 Tables, Washington D.C. 1978.

U.S. Department of Energy, Energy and Environmental Analysis Inc., Industrial Sector Technology Use Model (ISTUM), Vol. I-III, Washington D.C., 1978.

U.S. Department of Energy, State Energy Data Report, DOE/EIA-0214(79), 1981

U.S. Department of Energy, Phase One/Base Data for the Development of Energy Performance Standards for New Buildings, DOE Task Report TID-28825, January 12, 1978.

U.S. Department of Interior, "Desalting Handbook for Planners", prepared for U.S. DOE, Bureau of Reclamation, Office of Water Research and Technology, Report No. PB-253 755, Denver, Colorado, 1971.

U.S. Department of Interior, Saline Water Use and Disposal Opportunities, Special Report, prepared for U.S. DOE Bureau of Reclamation, 1981.

U.S. Energy Information Administration, Residential Energy Consumption Survey Characteristics of the Housing Stock and Households, February 1980.

U.S. Federal Energy Agency, Energy and U.S. Agriculture: 1974 Data Base, Vol. 1, prepared for U.S. Department of Agriculture, FEA/D-76/459, 1976.

U.S. Federal Energy Agency, Energy and U.S. Agriculture: 1974 Data Base, Vol. 2, Commodity Series of Energy Tables, prepared for U.S. Department of Agriculture, FEA/D-77/140, 1977.

Visher, S.S., Climatic Atlas of the United States, Harvard University Press, Cambridge, Mass., 1954.

Von Kalecsinsky, A., "Uber die ungarischen warmen und heissen kochsalzseen als naturliche warme-accumulatoren," Annalen der Physik, 4, 409 1902.

Washburn, E.W., ed., International Critical Tables of Numerical Data, Physics, Chemistry and Technology, McGraw-Hill, NY, 1926

Watt Engineering Ltd., On the Nature and Distribution of Solar Radiation, DOE Report HCP/T2552-01, 1978.

Weinberger, H., "The Physics of the Solar Pond," Solar Energy Journal, Vol. VIII, No. 2, pp. 45-56, 1964.

Willmott, C. J., and Vernon, M. T., "Solar climates of the Conterminous United States: A Preliminary Investigation," Solar Energy, Vol. 24, pp. 295-303, 1980.

Wilson, V., et al, Solar Industrial Process Heat - Industrial Applications and Attitudes (Draft), Solar Energy Research Institute, Golden, Colorado 84001, 1980.

Wittenberg, L.J., and Harris, M.J., "The Miamisburg Salt-Gradient Solar Pond," Proceedings, Non-Convective Solar Pond Workshop, pp. 13-1 to 13-15, July 1980.

APPENDIX A

DESCRIPTION OF A SALT-GRADIENT SOLAR POND

APPENDIX A

DESCRIPTION OF A SALT-GRADIENT SOLAR POND

A typical salt-gradient solar pond can be depicted by the schematic shown in Figure A-1. Pond area can range from several hundred square meters (a fraction of an acre) to several square kilometers (hundreds of acres). Pond depth usually varies between three and five meters, depending on the location and intended application. A pond is formed by excavation or embankment, or a combination thereof. The sides and bottom of a pond may or may not be lined with a plastic membrane or other impermeable liner, depending on the underlying soil conditions and the extent to which the surrounding environment requires protection against possible salt contamination.

As reflected by the name, a salt-gradient solar pond is filled with brine made of one or several salts, with the salt concentration varying from a few percent (by weight) at the surface to over twenty percent at the bottom. A typical slainity profile is depicted in Figure 1. Normally, the surface zone (0.15-0.30 m) and the bottom storage zone (1.5-3.5 m) have uniform salinity, and the gradient zone (1-1.5 m) has a salt concentration that increases with depth.

As solar radiation impinges on the pond surface, part of it is reflected and the remainder penetrates into and is absorbed by the pond. To understand how a salt-gradient solar pond traps the absorbed solar energy, one may first examine why an ordinary pond (i.e. as fresh water pond or a saline pond with uniform salinity) fails to do so. In an ordinary pond, when the water absorbs the incident solar radiation, its temperature increases and its density decreases. The water near the surface is readily cooled as heat is dissipated to the atmosphere. The warmer, lighter water at the bottom will then rise to the surface causing a fluid circulation commonly referred to as natural convection. At the surface, the heat contained in the warmer water is again transferred to the ambient air. Thus an ordinary pond cannot store the solar energy that it absorbs.

In a salt-gradient pond, due to the presence of the constructed salinity gradient, natural convection is suppressed because while water at the lower layer may be warmer, it has a higher salt content and therefore remains heavier than water at the upper layer. In addition, the salt-gradient zone prohibits longwave reradiation (as water is opaque to infrared radiation), and offers an effective conduction barrier (because the thermal conductivity of water is relatively low and the gradient zone is sufficiently thick). Consequently, the salt-gradient zone enables the pond to trap heat in the storage zone, where the temperature is allowed to increase steadily to a level substantially above ambient. Typically, temperature in a salt-gradient pond increases with depth, varying from slightly above ambient in the surface zone to 80-100°C in the storage zone during the fall. Some representative temperature profiles are illustrated in Figure A-1; note that they resemble the salinity profile qualitatively.

Both the surface and storage zone are convective (indicated in Figure A-1 by the convecting currents). The convecting currents in the surface zone are caused by wind, evaporation, precipitation, diurnal heating and cooling, and other physical factors, in ways that have not yet been fully

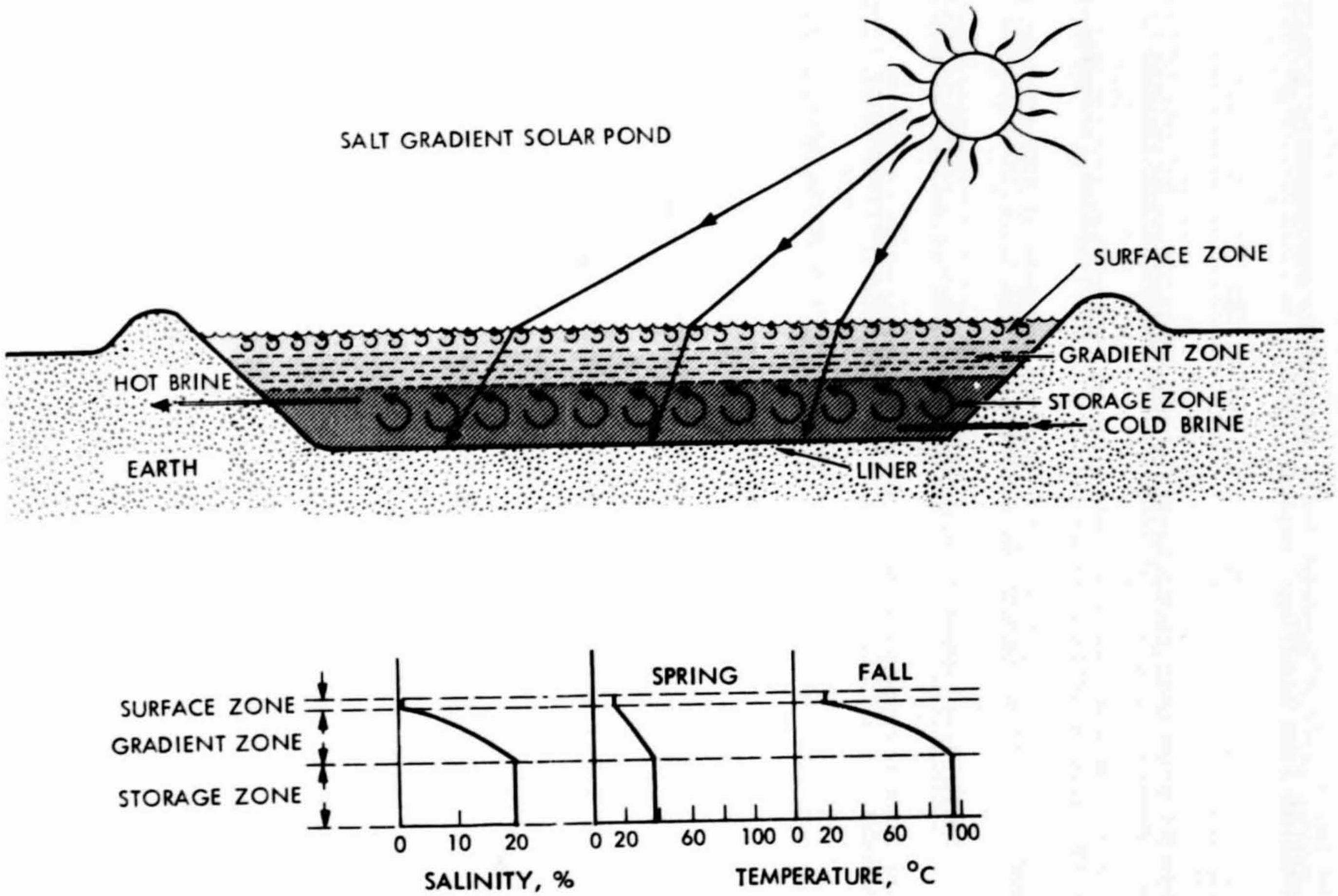

Figure A-1. Schematic of a Salt-Gradient Solar Pond with Typical Salinity and Temperature Profile

comprehended. The convecting currents in the storage zone, on the other hand, are induced by the buoyancy of heated bottom brine, the disturbance from heat extraction, etc. These phenomena also require further study in order to be fully understood. The gradient zone is stratified and nonconvective. It separates the two convective zones above and below, and prevents a full-depth natural convection from occuring, thereby serving its vital insulating function.

Heat trapped in the storage zone can be extracted by means of in-pond or out-of pond heat exchangers for both electric and thermal applications. Earlier experiences with in-pond heat exchangers have pointed out several disadvantages, such as corrosion and maintenance inconvenience. Particularly in large pond installations, out-of-pond heat exchangers are favored. Hot brine is withdrawn near the upper portion of the storage zone (Fig. A-1) and circulated through an out-of-pond heat exchanger where a working fluid receives heat from the brine to perform its designed duties. The cold brine is then returned to the pond near the bottom of the storage zone, usually on the opposite end from hot-brine withdrawal. Thermal energy thus extracted from the pond can be used to generate electricity or support a variety of thermal applications such as residential and commercial building space and water heating, industrial and agricultural process heating and desalination.

APPENDIX B

INSOLATION AND TEMPERATURE DATA

APPENDIX B

B.1 INSOLATION MEASUREMENTS AND CONTOUR GENERATION

B.1.1 BASIC CONCEPTS

The radiance of the solar radiation field at a given point in space, $R(\theta)$, represents the power per unit area normal to a specified direction, per unit solid angle, and is a function of the direction specified. Outside the earth's atmosphere this radiance has a value of

$$R(\theta) = 1.988 \times 10^4 \frac{\text{kW}}{\text{m}^2 \text{ steradian}}$$

in the direction of the solar disc, and is essentially zero for other directions.[1] This value is independent of the sun-earth distance and does not therefore have an annual time dependence. Being a measure of instrinsic solar properties it is also believed to be constant in time over very long periods.

The solar constant is obtained from the above radiance by integrating over the solar disc at a sun-earth distance of one astronomical unit and has the value of 1.354 kW/m^2. This value is also constant in time and does not depend upon direction.

In contrast to the simple conditions outside the earth's atmosphere, scattering and absorption phenomena result in a much more complex situation for locations at or near the earth's surface. These effects may be summarized by comparing the radiance at the earth's surface with that outside the earth's atmosphere, and such a comparison is shown in Figure B-1. It is seen that the terrestrial plot of $R(\theta)$ differs from the exoatmospheric plot in having a smaller value across the solar disc (1.5×10^4 kW/m^2 - steradian) and non-zero values for angles away from the disc.

B.1.2 INSOLATION MEASUREMENTS

Radiation measuring instruments (radiometers) are designed to measure power levels integrated over some fixed area and solid angle determined by the instrument geometry. The quantity they specify is the power per unit area normal to a specified direction, i.e., the irradiance over the given solid angle.

Insolation instruments differ in the solid angle used and the orientation of the instrument axis relative to the sun's center. They fall into two categories depending upon the values of these parameters.

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[1]This is an average value across the solar disc and ignores limb darkening.

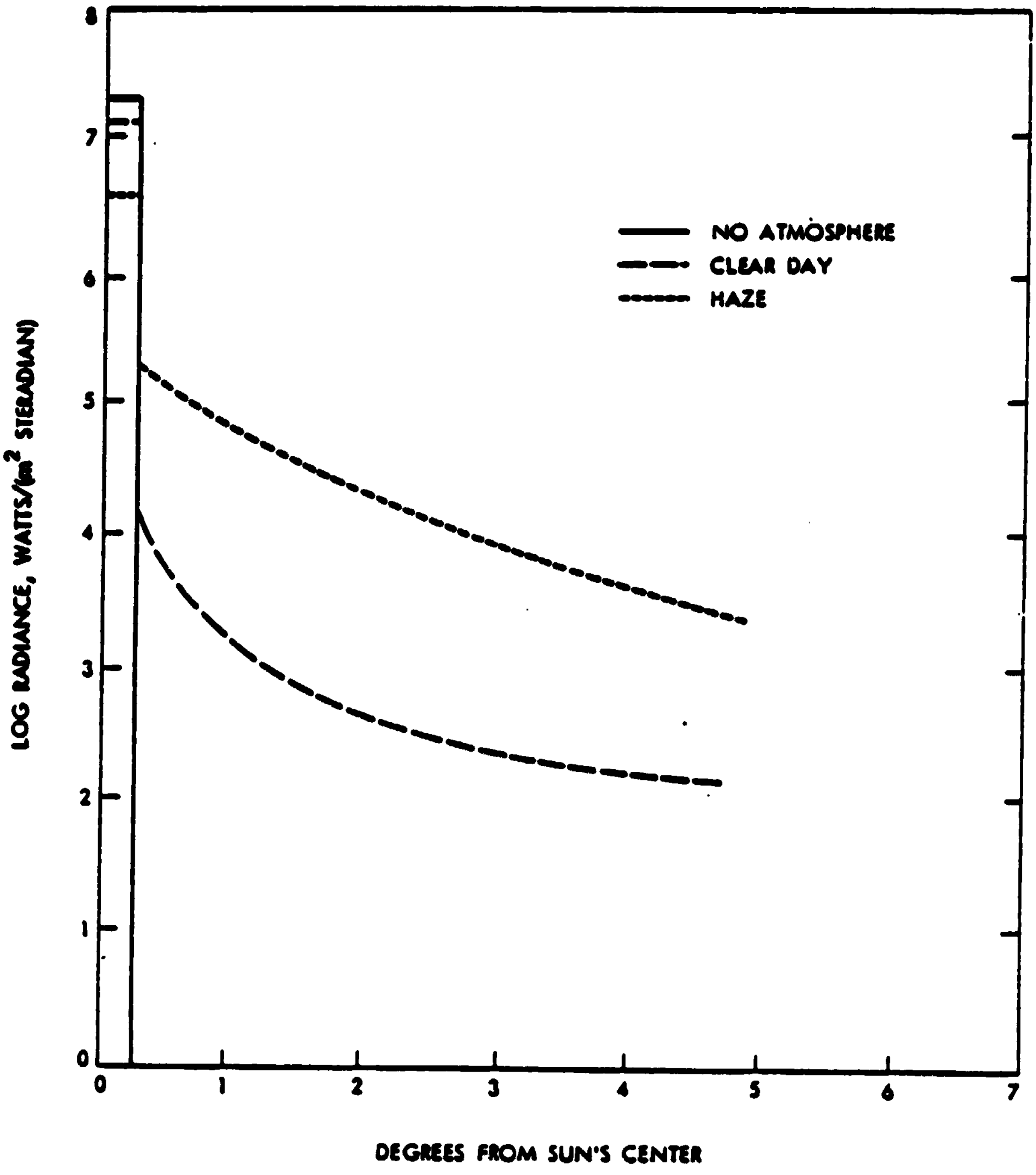

Figure B-1. Radiance of the Sky on and in the Region Surrounding the Solar Disc

The pyrheliometer has a relatively small field angle (typically 5-15°), and is maintained with its axis directed towards the sun by means of a clock-driven equatorial mount. The quantity thus measured is called the direct normal insolation and is related to the radiance shown in Figure B-1 by the following expression,

$$\Omega I_{DN} = \int R(\theta)\, d\,\Omega$$

where is the solid angle corresponding to the instrument's field angle.

The pyranometer has a 180° field angle and hence measures the insolation over a solid angle of 2π steradians. The orientation of the instrument axis is fixed relative to the local vertical direction and is usually parallel to this direction. In this case, the resulting measure is called the total horizontal insolation or total hemispheric insolation, I_{TH}. Since the direction to the sun's center relative to local vertical direction has a complex temporal dependence which, in turn, depends upon the geographical location, the relationship between I_{TH} and $R(\theta)$ is no longer simple.

The pyranometer is sometimes used with a shade ring which is mounted so as to prevent the direct radiation from the sun from reaching the instrument's entrance pupil. In this case the instrument measures the diffuse horizontal insolation, I_{dH}.

As can be seen from Figure B-1, a pyrheliometer with a total field angle of several degrees will measure not only the direct radiation from the sun (field angel $\sim 1/2°$), but also a certain amount of diffuse radiation coming from the sky. While generally small, this diffuse radiation which enters the pyrheliometer (called the circumsolar insolation, I_{cs}) can be significant in the presence of strong atmospheric scattering by water vapor. The dashed curve in Figure B-1 corresponds to a hazy atmosphere condition and illustrates the strong atmospheric scattering power of water vapor and submicron-size water droplets.

If the irradiance measured by a pyrheliometer with a 1/2° field angle is defined as the true direct normal component, I_{DNO}, then the quantities defined above are related as follows:

$$I_{DN} = I_{DNO} + I_{cs},$$

$$I_{TH} = I_{CN} \cos Z + I_{dH}$$

$$= (I_{DNO} + I_{cs}) \cos Z + I_{dH},$$

where

Z = zeuith angle of sun.

B.1.3 METHODS FOR GENERATING CONTOUR MAPS

The question of the effect which different interpolation schemes have on contours produced from a given data set does not appear to have been

considered by those presenting such maps because little or no mention is generally made as to which of the many possible methods for generating contours has actually been used. The discussion which follows presents some of the basic problems that should be considered and provides a number of specific examples which demonstrate the rather large variation that can be obtained by using different methods for the generation of contour maps.

Two basic approaches may be used to generate contours from a given set of randomly distributed points at which the zenith angles of the sun are specified. In the first, the points are interconnected to form a net of triangles, and points on the contour lines are determined by linear interpolation of the z-values along each of the sides of each triangle. Common z-value points are then joined by a smooth curve. The second approach begins by fitting a smooth surface to the z-values given, and then drawing the contours.

In the first approach, there is ambiguity in the choice of interconnections in that there is no unique way to join a set of randomly distributed points to form triangles. Thus, different sets of triangles will result in different contours. Also, any of several different methods can be used to draw smooth curves through the common z-value points found by interpolation and, generally speaking, each different method will result in a slightly different set of contours.

In the surface fitting approach, all of the ambiguity is concentrated in the surface fitting algorithm since, once a smooth surface is obtained, the contours are unique.[2]

The number of ways a smooth surface can be fitted to a randomly distributed set of z-values is virtually unlimited. Some common methods employ splined cubic functions while others adopt an iterative approach in which the surface is contrained by some simple partial differential equation (Poisson's equation, the biharmonic equation). Even with a given method, the resulting surface and, hence, the contours depend upon the exact manner in which the algorithm is applied. For example, one method of fitting a splined cubic function involves the initial formation of a triangular net, as in the linear interpolation scheme described earlier. Since the polygon formed in the (x,y) plane must be convex in this method, one must usually supply additional data points to accomplish this, and since these points must themselves be determined by some method of interpolation or extrapolation, and additional uncertainty is introduced into the final contour map. Actual computer runs show that such schemes tend to produce questionable edge effects which depend upon the exact choice made for assinging z-values to the extra points.

Another important consideration that enters into the surface-fitting problem is the extent to which the final surface actually coincides with the original data points. Many techniques of smoothing

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[2]Actually, one may view the triangle method as a crude surface fit which would produce a unique set of linearly segmented contours.

introduce departures from a perfect fit unless the algorithm explicitly prevents this by constraining the surface to pass through the original points as the iteration proceeds. Such departures may or may not be desirable depending on the data and the purpose for which the contours are to be used. For example, if, as is often the case, the existing data constitute a severely under-sampled set, a smoothed surface which does not necessarily provide a perfect fit might be more representative of average trends than one which does. For example, a random sampling that happens to select adjacent high and low z-values would lead to unrepresentative contours if the surface were constrained to pass through these points.

B.1.4 USE OF THE JPL IMAGE PROCESSING LAB

The insolation contour maps presented in this report were prepared using the digital image processing facilities of the Image Processing Lab at JPL. The algorithm used generates gray level values from the rehabilitated insolation data for each measuring station, and then produces from these weighted -functions a discontinuous gray level surface by assigning to each point on the map a level equal to that of the nearest data point. This discontinuous surface is then spatially filtered by convolution with a box filter of specified size.

The result of this procedure is a smooth surface for which the gray level corresponds to insolation level, a value of 8 kWh/m^2-day corresponding to white, and a value of 0 to black. Isoinsolation contours are then generated by assigning all surface points having a given gray level the value of 8 (white), and this is done at intervals of 0.5 kWh/m^2-day.

The three maps presented were generated by using increasingly large box filters resulting in increased amounts of smoothing, the data set used for generation being the same in each case. The first map, Figure B-2, has the least amount of smoothing and consequently corresponds most closely to the original data. Conversely, in Figure B-4 the smoothing is considerable, and small discrepancies can be discerned by comparing the contour values with the data values listed in Appendix B, Section B.2. Thus, the three different maps provide a visual indication of the effect of different degrees of smoothing applied to the same data, and serve as a guide in assessing the effects of different surface generating algorithms.

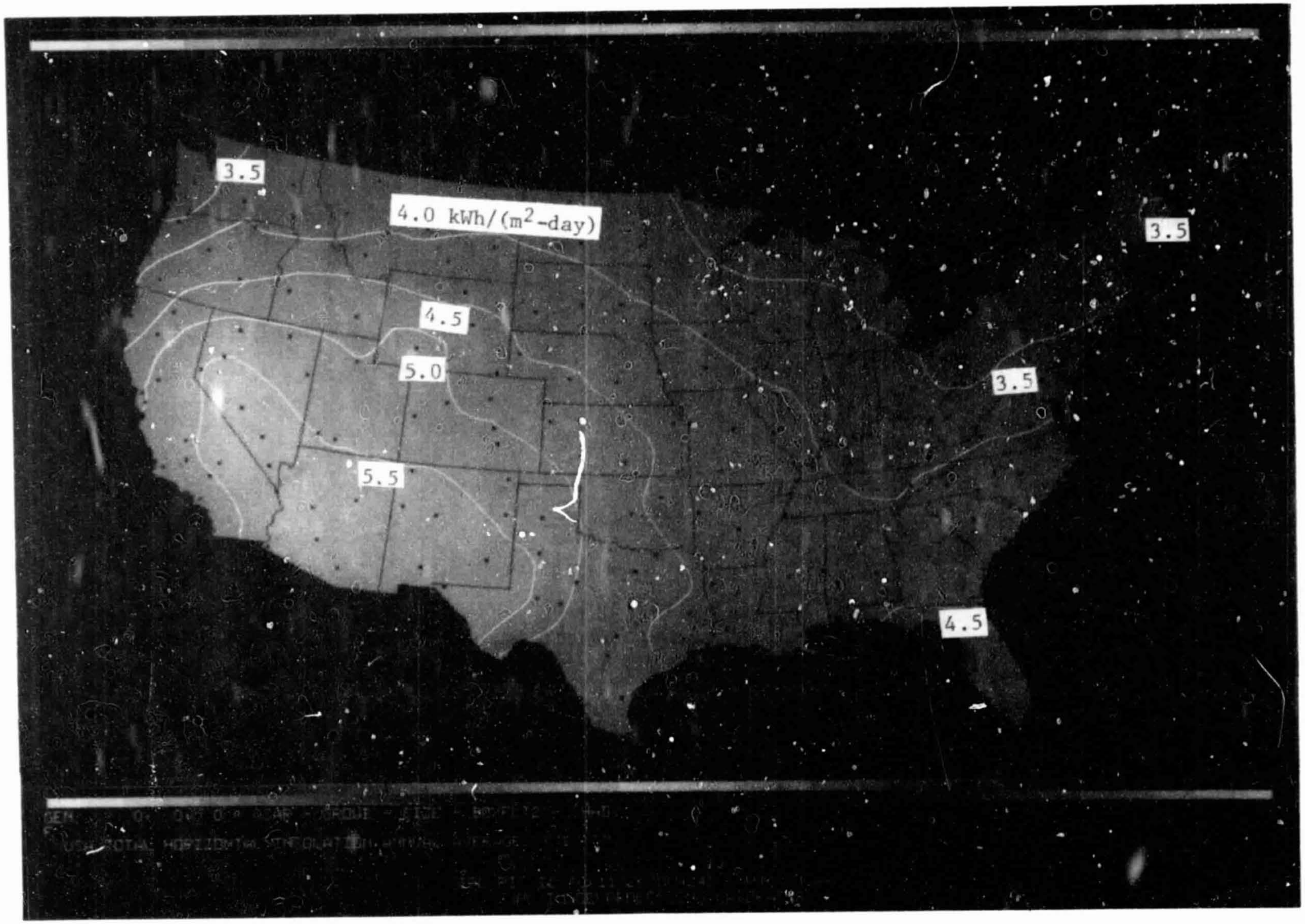

Figure B-2. The Effect of Data Smoothing on Insolation Contour Maps: Least Smoothing

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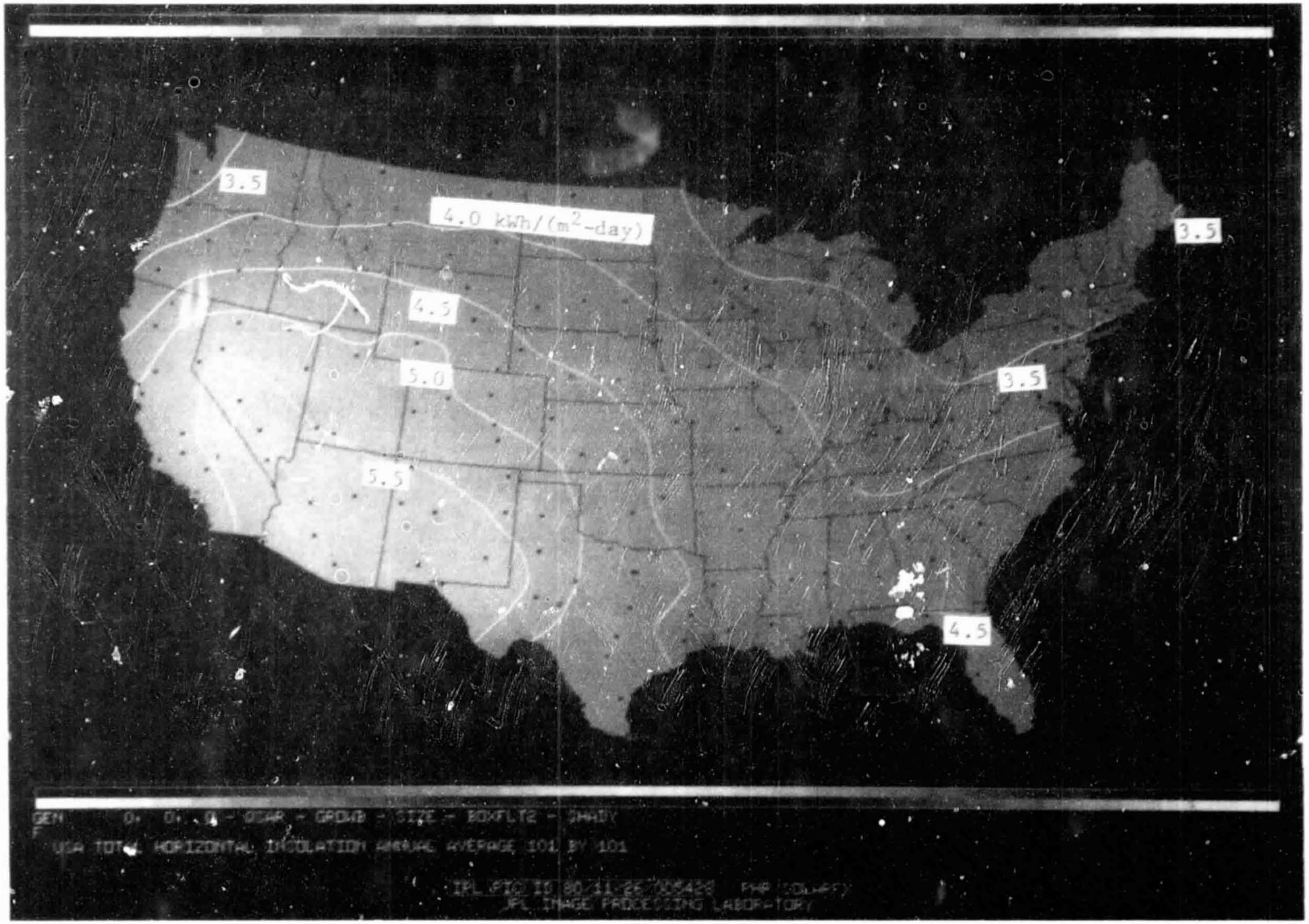

Figure B-3. The Effects of Data Smoothing on Insolation Contour Maps: Moderate Smoothing

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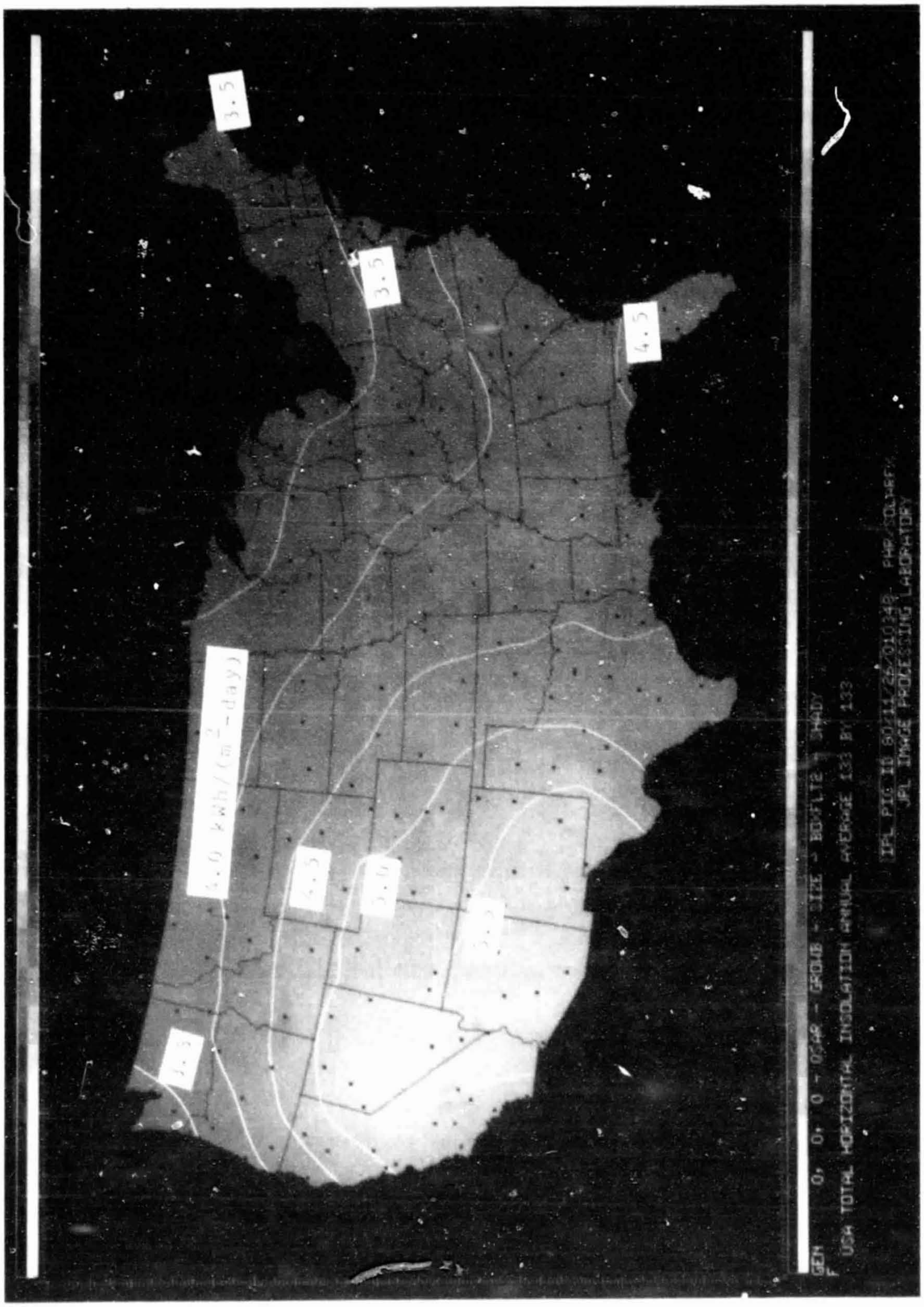


Figure B-4. The Effect of Data Smoothing on Insolation Contour Maps: Considerable Smoothing

B.2. MONTHLY AVERAGE INSOLATION AND TEMPERATURE DATA[a] for 233 WEATHER STATIONS[b]

[a]Temperature is in °F, Insolation is in Langleys/day, Elevation is in ft.
[4]Source: Cinquemani, et al, 1978.

STATE:	Alaska		Alaska		Alaska		Alaska		Alaska	
STATION:	Adak		Annette		Barrow		Bethel		Bettles	
LATITUDE:	5153N		5502N		7118N		6047N		6655N	
LONGITUDE:	17638W		13134W		15647W		16148W		15131W	
ELEVATION:	5		34		4		46		205	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	0.0	62.7	33.5	48.3	-14.7	0.0	5.1	26.3	-13.2	2.7
Feb	0.0	117.3	36.7	101.6	-18.6	20.0	8.2	85.9	-7.8	46.7
Mar	0.0	194.3	38.3	194.5	-15.2	133.1	11.4	200.3	1.5	167.0
Apr	0.0	280.1	42.8	311.8	-0.9	284.9	24.5	325.6	20.5	333.2
May	0.0	320.0	49.4	399.6	19.1	309.2	40.1	394.2	41.7	460.8
Jun	0.0	320.6	54.6	397.5	33.0	414.3	51.6	411.9	56.2	503.8
Jul	0.0	303.9	57.8	390.4	38.7	395.8	54.7	349.8	57.9	423.9
Aug	0.0	257.3	58.3	315.3	37.6	232.1	52.3	249.5	51.9	291.6
Sep	0.0	206.0	54.0	220.3	30.3	112.4	45.0	190.1	40.0	182.3
Oct	0.0	143.3	46.9	114.5	15.3	34.1	30.2	100.5	20.0	68.4
Nov	0.0	63.5	39.9	59.3	-0.5	1.0	17.2	36.7	-1.4	10.9
Dec	0.0	50.8	35.9	33.2	-12.3	0.0	4.4	13.2	-12.2	0.0
Ann	0.0	195.0	45.7	215.5	9.3	161.4	28.7	198.7	21.3	207.6

STATE:	Alaska		Alaska		Alaska		Alaska		Alaska	
STATION:	Big Delta		Fairbanks		Gulkana		Homer		Juneau	
LATITUDE:	6400N		6449N		6209N		5938N		5822N	
LONGITUDE:	14544W		14752W		14527W		15130W		13435W	
ELEVATION:	388		138		481		22		7	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	-4.9	12.5	-11.9	8.2	-7.3	19.7	21.4	33.0	23.5	31.5
Feb	3.4	67.0	-2.5	60.1	3.9	77.7	24.9	90.6	28.0	76.6
Mar	12.3	192.9	9.5	182.9	14.5	205.5	27.6	206.0	31.9	165.5
Apr	29.4	337.5	28.9	323.8	30.2	353.8	35.0	338.6	38.9	283.7
May	46.3	452.9	47.3	435.0	43.8	437.8	42.3	429.3	46.8	350.3
Jun	57.1	483.5	59.0	475.2	54.2	476.8	48.7	474.8	53.2	383.7
Jul	59.4	437.7	60.7	418.4	56.9	437.3	52.3	433.5	55.7	346.7
Aug	54.8	333.4	55.4	303.3	53.2	339.4	52.4	322.4	54.3	267.0
Sep	43.6	208.0	44.4	192.4	43.6	215.6	47.0	214.7	49.2	173.3
Oct	25.2	88.5	25.2	79.4	26.8	105.8	37.4	118.6	41.8	86.9
Nov	6.9	25.1	2.8	20.1	6.1	31.5	28.2	47.6	32.5	40.3
Dec	-4.2	2.5	-10.4	0.7	-5.1	7.7	21.4	17.4	27.3	16.8
Ann	27.5	220.1	25.7	208.3	26.8	225.7	36.5	227.2	40.3	185.2

STATE:	Alaska		Alaska		Alaska		Alaska		Alaska	
STATION:	King Salmon		Kodiak		Kotzebue		McGrath		Nome	
LATITUDE:	5841N		5745N		6652N		6258N		6430N	
LONGITUDE:	15639W		15220W		16238W		15537W		16526W	
ELEVATION:	15		34		5		103		7	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	13.4	39.7	30.4	40.5	-3.7	2.3	-8.9	15.7	6.0	8.1
Feb	16.6	102.3	31.4	96.5	-4.3	44.5	-0.2	70.1	5.2	60.7
Mar	20.4	216.8	32.1	212.1	-0.5	161.2	8.9	187.9	7.4	171.2
Apr	31.5	327.0	36.9	327.6	13.0	320.4	26.5	322.2	18.9	321.6
May	42.6	402.1	43.2	373.3	30.8	445.6	44.1	403.7	34.8	426.7
Jun	50.7	417.9	49.7	415.0	43.5	498.2	55.7	430.4	45.5	475.6
Jul	54.5	375.3	54.1	382.0	52.9	414.6	58.2	374.2	50.1	383.6
Aug	53.8	283.6	54.9	315.8	50.7	283.3	53.5	276.4	49.2	269.3
Sep	47.3	211.0	50.0	215.4	41.1	175.9	43.8	188.5	42.1	182.6
Oct	33.6	128.6	40.7	132.7	23.6	69.5	25.3	86.0	28.5	83.0
Nov	22.1	55.3	34.8	56.0	7.7	8.9	5.0	27.2	15.6	17.6
Dec	11.7	24.7	29.9	26.3	-3.9	0.0	-9.2	5.3	4.4	0.8
Ann	33.2	215.3	40.7	216.1	20.9	202.0	25.2	199.0	25.6	200.1

STATE:	Alaska		Alaska		Alabama		Alabama		Alabama	
STATION:	Summit		Yakutat		Burmingham		Mobile		Montgomery	
LATITUDE:	6320N		5931N		3334N		304[illegible]N		3218N	
LONGITUDE:	14908W		13940W		8645W		8815W		8624W	
ELEVATION:	733		9		192		67		62	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	1.6	15.2	24.2	27.2	44.2	191.7	51.2	224.6	47.5	203.9
Feb	6.6	68.0	28.0	72.0	46.9	262.3	54.0	298.3	50.6	274.8
Mar	11.2	189.3	30.3	169.1	53.3	351.6	59.4	381.8	56.5	363.6
Apr	23.5	336.2	36.1	285.0	63.2	453.9	67.9	467.0	65.2	469.0
May	37.4	442.9	43.3	343.8	70.5	503.7	74.8	507.8	72.4	514.7
Jun	49.0	442.9	49.7	364.7	77.4	520.4	80.3	506.8	78.9	535.0
Jul	52.0	382.8	53.4	327.5	79.9	490.9	81.6	465.3	81.0	499.4
Aug	48.6	283.0	52.9	255.6	79.2	467.6	81.5	445.2	80.7	473.5
Sep	39.9	190.8	48.4	172.1	73.9	394.6	77.5	393.1	76.0	398.1
Oct	24.0	93.4	40.7	93.5	63.3	328.4	68.9	352.3	65.8	342.2
Nov	9.7	29.0	32.2	36.7	52.1	232.7	58.5	259.1	55.0	248.3
Dec	2.9	4.5	26.7	13.9	45.2	179.4	52.9	205.9	48.5	195.1
Ann	25.5	206.5	38.8	180.1	62.4	364.7	67.4	375.6	64.8	376.5

STATE:	Arkansas		Arkansas		Arizona		Arizona		Arizona	
STATION:	Fort Smith		Little Rock		Phoenix		Prescott		Tucson	
LATITUDE:	3520N		3444N		3326N		3439N		3207N	
LONGITUDE:	9422W		9214W		11201W		11226W		11056W	
ELEVATION:	141		81		339		1531		779	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	39.0	201.7	39.5	198.4	51.2	277.0	37.1	275.6	50.9	298.1
Feb	43.3	271.0	42.9	272.0	55.1	372.7	40.5	362.1	53.5	388.4
Mar	50.3	355.8	50.3	356.1	59.7	492.1	44.3	482.0	57.6	505.7
Apr	62.2	438.3	61.7	436.9	67.7	638.7	52.0	617.1	65.5	641.0
May	70.1	518.6	69.8	523.3	76.3	726.0	60.4	713.1	73.6	724.6
Jun	78.0	566.8	78.1	571.4	84.6	743.0	69.1	749.2	82.1	740.4
Jul	82.2	560.2	81.4	551.2	91.2	674.5	75.5	626.4	86.3	635.0
Aug	81.4	509.2	80.6	504.7	89.1	621.9	73.0	567.4	83.8	592.1
Sep	74.0	407.3	73.3	411.8	83.8	546.7	68.1	530.2	80.1	536.7
Oct	63.2	325.7	62.4	333.2	72.2	427.6	57.2	418.5	70.1	434.5
Nov	50.4	231.0	50.3	229.8	59.8	312.1	45.8	309.2	58.5	327.8
Dec	41.5	184.9	41.6	182.7	52.5	252.8	38.6	251.4	52.0	270.1
Ann	61.3	380.9	61.0	381.0	70.3	507.1	55.1	491.8	67.8	507.9

STATE:	Arizona		Arizona		California		California		California	
STATION:	Winslow		Yuma		Arcata		Bakersfield		China Lake	
LATITUDE:	3501N		3240N		4059N		3525N		3541N	
LONGITUDE:	11044W		11436W		12406W		11903N		11741N	
ELEVATION:	1488		63		69		150		681	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	32.6	267.1	55.4	297.3	0.0	143.4	47.5	207.9	0.0	246.7
Feb	39.1	359.9	59.4	391.5	0.0	215.1	52.4	298.9	0.0	333.5
Mar	44.8	482.8	63.9	520.6	0.0	307.3	56.6	432.6	0.0	470.6
Apr	53.7	619.3	71.2	654.5	0.0	430.4	62.7	568.2	0.0	605.8
May	62.7	703.8	78.7	740.0	0.0	499.8	69.8	680.6	0.0	691.3
Jun	71.8	735.5	85.8	763.3	0.0	532.1	76.9	745.7	0.0	745.1
Jul	78.3	636.6	93.7	665.5	0.0	490.3	83.9	727.9	0.0	708.6
Aug	76.1	580.6	92.8	631.8	0.0	428.4	81.6	656.6	0.0	709.6
Sep	69.5	522.9	87.1	556.3	0.0	364.1	76.6	540.3	0.0	537.0
Oct	57.3	410.3	75.9	440.2	0.0	253.8	66.9	395.6	0.0	399.4
Nov	43.2	303.6	63.5	329.5	0.0	160.8	56.0	255.6	0.0	280.4
Dec	33.8	242.6	56.3	271.3	0.0	127.4	47.9	183.7	0.0	228.1
Ann	55.3	488.8	73.7	521.8	0.0	329.4	64.9	474.5	0.0	496.3

STATE:	California		California		California		California		California	
STATION:	Daggett		El Toro		Fresno		Long Beach		Los Angeles	
LATITUDE:	3452N		3340N		3646N		3349N		3356N	
LONGITUDE:	11647W		11744W		11943W		11809W		11824W	
ELEVATION:	588		116		100		17		32	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	47.3	259.9	0.0	256.9	45.3	178.1	54.2	251.6	54.5	251.2
Feb	52.0	347.4	0.0	335.3	49.9	274.6	55.5	329.6	55.6	329.3
Mar	56.7	480.7	0.0	436.8	53.9	424.7	57.2	436.7	56.5	439.1
Apr	64.3	616.8	0.0	523.1	60.3	567.6	60.6	525.6	58.8	529.2
May	72.3	702.8	0.0	561.5	67.4	673.7	64.1	560.0	61.9	558.7
Jun	80.1	750.3	0.0	595.1	73.9	741.3	67.3	580.4	64.5	574.8
Jul	87.3	706.2	0.0	641.1	80.6	728.3	72.2	623.8	68.5	625.9
Aug	85.5	646.3	0.0	584.5	78.3	657.3	73.3	569.6	69.5	564.1
Sep	79.2	544.6	0.0	471.2	73.8	538.5	71.8	461.4	68.7	456.1
Oct	68.1	411.1	0.0	368.0	64.2	387.7	66.9	359.8	65.2	357.2
Nov	55.5	294.3	0.0	278.4	53.5	241.0	60.6	272.2	60.5	272.3
Dec	48.0	237.6	0.0	235.8	45.8	155.7	55.5	229.7	56.9	230.2
Ann	66.4	499.9	0.0	440.6	62.3	464.1	63.3	433.4	61.7	432.3

STATE:	California		California		California		California		California	
STATION:	Mt. Shasta		Needles		Oakland		Pt. Mugu		Red Bluff	
LATITUDE:	4119N		3446N		3744N		3407N		4009N	
LONGITUDE:	12219W		11437W		12212W		11907W		12215W	
ELEVATION:	1093		270		2		4		108	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	33.6	152.1	51.6	267.1	48.6	192.0	0.0	251.5	45.2	154.7
Feb	37.8	232.6	56.5	367.1	51.9	276.0	0.0	330.9	50.0	242.1
Mar	40.4	339.1	61.6	495.1	53.7	395.0	0.0	443.7	53.2	367.3
Apr	46.3	476.3	70.4	628.5	56.1	521.4	0.0	529.2	59.5	518.1
May	53.3	592.9	79.6	719.3	58.9	599.8	0.0	547.4	67.4	644.2
Jun	60.0	660.8	88.3	757.1	61.9	637.4	0.0	557.3	75.5	705.2
Jul	67.8	699.1	95.4	689.3	63.1	630.0	0.0	574.6	82.3	724.7
Aug	66.0	600.3	93.3	617.8	63.5	556.8	0.0	524.8	79.9	626.8
Sep	61.2	470.7	86.9	546.4	64.5	461.4	0.0	436.1	75.3	500.5
Oct	51.4	313.3	74.3	417.0	61.1	328.8	0.0	351.6	65.0	333.0
Nov	41.7	178.8	60.7	304.8	55.3	223.0	0.0	273.0	53.7	191.6
Dec	35.5	137.0	52.7	247.7	49.9	175.5	0.0	232.2	46.4	138.5
Ann	49.6	404.4	72.6	504.8	57.4	416.4	0.0	421.0	62.8	428.9

STATE:	California		California		California		California		California	
STATION:	Sacramento		San Diego		San Francisco		Santa Maria		Sunnyvale	
LATITUDE:	3831N		3244N		3737N		3454N		3725N	
LONGITUDE:	12130W		11710W		12223W		12027W		12204W	
ELEVATION:	8		9		5		72		12	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	45.1	161.9	55.2	264.7	48.3	191.9	50.5	231.6	0.0	200.1
Feb	49.8	254.8	56.7	343.5	51.2	273.8	52.0	309.5	0.0	281.4
Mar	53.0	395.6	58.0	442.6	53.0	394.7	52.8	429.1	0.0	402.9
Apr	58.3	543.5	60.7	525.3	55.3	520.8	54.9	521.1	0.0	527.2
May	64.3	660.4	63.3	543.3	58.3	603.7	57.1	580.6	0.0	617.6
Jun	70.5	728.0	65.5	559.4	61.6	644.7	59.6	637.0	0.0	665.3
Jul	75.2	729.1	69.6	593.1	62.5	648.7	62.1	635.0	0.0	662.2
Aug	74.1	642.4	71.4	558.0	63.0	574.1	62.3	571.2	0.0	587.8
Sep	71.5	517.2	69.9	465.8	64.1	472.5	62.6	469.3	0.0	477.3
Oct	63.3	356.7	66.1	372.5	61.0	332.6	60.4	367.1	0.0	338.6
Nov	53.0	212.1	60.8	288.2	55.3	222.8	56.1	264.1	0.0	228.7
Dec	45.8	146.0	56.7	245.1	49.7	174.2	51.8	218.0	0.0	179.1
Ann	60.3	445.6	62.9	433.5	56.9	421.2	56.9	436.1	0.0	430.7

STATE:	Colorado		Colorado		Colorado		Colorado		Colorado	
STATION:	Colo. Springs		Denver		Eagle		Grd. Junction		Pueblo	
LATITUDE:	3849N		3945N		3939N		3907N		3817N	
LONGITUDE:	10443N		10452W		10655W		10832W		10431W	
ELEVATION:	1881		1625		1985		1475		1439	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	28.6	241.6	29.9	227.9	18.0	204.6	26.6	214.6	30.1	242.6
Feb	31.3	319.6	32.8	305.7	23.3	292.4	33.6	303.5	34.7	317.8
Mar	35.3	420.4	37.0	415.1	31.1	407.3	41.2	421.4	40.0	424.2
Apr	46.2	523.8	47.5	509.8	41.9	524.2	51.7	538.8	51.7	530.5
May	55.5	577.4	57.0	579.1	51.3	611.7	62.2	645.5	61.1	586.6
Jun	64.6	642.5	66.0	637.6	58.9	680.5	71.3	704.8	70.7	660.3
Jul	70.7	600.0	73.0	616.4	65.9	646.8	78.7	668.7	76.4	627.0
Aug	69.1	549.4	71.6	554.4	63.7	565.2	75.4	591.8	74.5	570.1
Sep	60.9	477.2	62.8	468.4	55.6	479.2	67.2	497.6	66.2	482.7
Oct	50.5	368.5	52.0	352.7	44.8	354.6	54.9	364.8	54.5	369.1
Nov	37.5	256.1	39.4	239.7	30.9	235.6	39.8	249.0	40.8	258.7
Dec	31.0	212.1	32.6	198.5	20.3	187.4	29.5	198.4	33.0	212.2
Ann	48.4	432.4	50.1	425.4	42.2	432.5	52.7	449.9	52.8	440.2

STATE:	Connecticut		Cuba		Dist. of Col.		Delaware		Florida	
STATION:	Hartford		Guantanamo		Wash.-Sterling		Wilmington		Apalachicola	
LATITUDE:	4156N		1954N		3857N		3940N		2944N	
LONGITUDE:	7241W		7509W		7727W		7536W		8502W	
ELEVATION:	55		16		88		24		6	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	24.8	129.5	0.0	380.6	32.1	155.2	32.0	155.0	53.7	231.3
Feb	26.8	193.9	0.0	447.0	33.8	221.2	33.6	224.3	55.8	305.4
Mar	35.6	265.4	0.0	522.5	41.8	305.2	41.6	311.7	60.7	399.8
Apr	47.7	356.7	0.0	575.0	53.1	395.7	52.3	401.5	68.3	509.7
May	58.3	425.5	0.0	552.7	62.6	466.0	62.4	463.9	74.9	567.1
Jun	67.8	457.2	0.0	531.9	71.1	515.6	71.4	510.6	80.0	542.0
Jul	72.7	447.3	0.0	564.8	75.3	493.0	75.8	494.4	81.4	491.9
Aug	70.4	385.6	0.0	543.2	73.6	438.7	74.1	438.0	81.5	457.7
Sep	62.8	313.1	0.0	494.7	66.9	363.5	67.9	357.4	78.6	416.5
Oct	52.6	231.3	0.0	429.8	55.9	272.3	57.2	266.9	70.8	372.0
Nov	41.3	134.9	0.0	388.4	44.7	176.6	45.7	174.8	61.1	282.1
Dec	28.2	104.4	0.0	356.1	34.0	130.5	34.7	132.5	55.2	221.8
Ann	49.1	287.1	0.0	482.2	53.7	327.8	54.0	327.6	68.5	399.8

STATE:	Florida		Florida		Florida		Florida		Florida	
STATION:	Daytona Beach		Jacksonville		Miami		Orlando		Tallahassee	
LATITUDE:	2911N		3030N		2548N		2833N		3023N	
LONGITUDE:	8103W		8142W		8016W		8120W		8422W	
ELEVATION:	12		9		2		36		21	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	58.4	260.00	54.6	244.1	67.2	286.8	60.3	271.1	52.6	237.8
Feb	59.6	329.0	56.3	315.8	67.8	356.4	61.5	337.3	54.8	308.6
Mar	63.9	419.9	61.2	412.8	71.3	434.9	65.9	429.2	60.3	401.3
Apr	69.7	511.0	68.1	503.3	75.0	504.3	71.3	514.8	67.9	494.5
May	75.0	533.8	74.3	530.6	78.0	500.1	76.4	539.5	74.8	525.1
Jun	79.4	495.3	79.2	511.4	81.0	463.3	80.2	496.7	80.0	510.7
Jul	81.0	483.9	81.0	488.8	82.3	478.3	81.4	488.6	81.1	474.2
Aug	81.1	456.2	81.0	459.5	82.9	442.1	81.8	453.8	81.1	454.4
Sep	79.5	400.8	78.2	391.2	81.7	395.0	80.1	406.0	78.1	405.0
Oct	73.3	339.4	70.5	331.8	77.8	353.3	74.3	353.8	69.3	357.4
Nov	65.1	280.9	61.2	270.1	72.2	303.4	66.6	297.3	58.9	273.5
Dec	59.6	236.1	55.4	221.8	68.3	276.4	61.5	251.2	53.2	220.5
Ann	70.5	395.5	68.4	390.1	75.5	399.5	71.8	403.3	67.7	388.6

STATE:	Florida		Florida		Georgia		Georgia		Georgia	
STATION:	Tampa		W. Palm Beach		Atlanta		Augusta		Macon	
LATITUDE:	2758N		2641N		3339N		3322N		3242N	
LONGITUDE:	8232W		8006W		8426W		8158W		8339W	
ELEVATION:	3		6		315		45		110	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	60.4	274.1	65.5	271.2	42.4	194.6	45.8	203.7	47.8	208.6
Feb	61.8	341.6	66.1	334.4	45.0	262.8	48.3	275.4	50.4	276.6
Mar	66.0	432.3	69.8	422.1	51.1	353.6	54.6	363.0	56.5	369.8
Apr	72.0	517.7	73.9	492.2	61.1	457.4	63.8	468.8	65.8	470.9
May	77.2	542.0	77.5	500.3	69.1	502.8	71.7	505.9	73.5	511.3
Jun	81.0	501.1	80.5	462.8	75.6	519.1	78.2	516.4	79.6	520.6
Jul	81.9	475.4	81.9	482.5	78.0	491.5	80.4	489.2	81.4	484.2
Aug	82.2	448.4	82.3	451.2	77.5	463.4	79.6	452.2	80.9	465.9
Sep	80.8	404.7	81.5	384.8	72.3	385.7	74.2	382.4	75.8	390.3
Oct	74.7	365.2	77.2	332.0	62.4	325.5	64.1	330.8	65.7	338.3
Nov	66.8	300.5	71.0	287.5	51.4	239.5	53.7	248.6	55.2	254.9
Dec	61.6	253.7	66.8	259.9	43.5	182.9	46.4	195.6	48.3	197.7
Ann	72.2	404.7	74.5	390.1	60.8	364.9	63.4	369.3	65.1	374.1

STATE:	Georgia		Hawaii		Hawaii		Hawaii		Hawaii	
STATION:	Savannah		Barbers Point		Hilo		Honolulu		Lihue	
LATITUDE:	3208N		2119N		1943N		2120N		2159N	
LONGITUDE:	8112W		15804W		15504W		15755W		15921W	
ELEVATION:	16		10		11		5		45	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	49.9	215.6	0.0	327.6	71.2	303.7	72.3	320.0	71.2	299.2
Feb	52.1	283.1	0.0	390.9	71.0	338.0	72.3	378.8	71.2	352.5
Mar	58.0	379.3	0.0	446.2	71.1	365.8	73.0	439.9	71.7	400.2
Apr	66.1	477.8	0.0	497.3	72.2	389.2	74.8	487.1	73.3	445.0
May	73.3	502.4	0.0	535.0	73.5	421.2	76.9	528.8	75.5	494.7
Jun	79.1	500.3	0.0	549.1	74.6	449.9	78.9	543.7	77.5	506.6
Jul	81.1	483.8	0.0	547.4	75.3	440.6	80.1	543.1	78.4	505.2
Aug	80.6	439.7	0.0	534.7	75.9	431.9	80.7	533.4	79.1	493.2
Sep	76.2	369.9	0.0	492.2	75.6	419.6	80.4	491.0	78.8	472.6
Oct	67.1	330.0	0.0	421.7	75.0	372.2	78.9	417.8	77.3	393.1
Nov	57.1	255.3	0.0	352.5	73.5	299.7	76.5	343.4	75.2	313.1
Dec	50.4	204.4	0.0	316.2	71.6	276.5	73.7	307.2	72.5	285.6
Ann	65.9	370.1	0.0	450.9	73.4	375.7	76.6	444.5	75.1	413.4

STATE:	Iowa		Iowa		Iowa		Iowa		Idaho	
STATION:	Burlington		Des Moines		Mason City		Sioux City		Boise	
LATITUDE:	4047N		4132N		4309N		4224N		4334N	
LONGITUDE:	9107W		9339W		4224W		9623W		11613W	
ELEVATION:	214		294		336		336		874	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	22.9	157.1	19.4	157.5	14.2	150.2	18.0	154.2	29.0	131.6
Feb	27.3	232.9	24.2	233.5	18.5	226.8	23.4	228.3	35.5	227.8
Mar	36.9	316.0	33.9	320.2	29.0	316.8	33.2	317.5	41.1	353.7
Apr	51.3	417.2	49.5	422.2	45.7	411.9	49.4	428.0	49.0	495.5
May	61.8	508.7	60.9	506.5	57.4	514.1	60.9	515.7	57.4	617.5
Jun	71.4	575.3	70.5	576.3	67.2	573.4	70.3	576.0	64.8	668.1
Jul	75.4	565.5	75.1	568.7	71.3	565.3	75.3	575.6	74.5	708.7
Aug	73.9	495.9	73.3	495.8	69.9	497.1	73.5	500.5	72.2	595.8
Sep	65.4	384.2	64.3	388.9	60.2	381.2	63.4	385.5	63.1	471.2
Oct	55.3	287.7	54.3	289.6	50.5	274.1	53.1	281.6	52.1	308.6
Nov	39.8	180.0	37.8	178.6	33.6	162.7	36.3	174.3	39.8	170.4
Dec	27.6	130.4	25.0	132.1	20.1	120.2	23.5	127.3	32.1	118.6
Ann	50.8	354.3	49.0	355.8	44.8	349.5	48.4	355.4	50.9	405.6

STATE:	Idaho		Idaho		Illinois		Illinois		Illinois	
STATION:	Lewiston		Pocatello		Chicago		Moline		Springfield	
LATITUDE:	4623N		4255N		4147N		4127N		3950N	
LONGITUDE:	11701W		11236W		8745W		9031W		8940W	
ELEVATION:	438		1365		190		181		187	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	31.2	92.1	23.2	146.2	24.3	137.5	21.5	145.1	26.7	158.6
Feb	38.1	165.2	29.4	239.2	27.4	206.0	25.7	220.2	30.4	233.5
Mar	42.9	276.6	35.4	372.0	36.8	300.2	35.7	303.4	39.4	310.0
Apr	50.3	389.2	45.3	493.8	49.9	395.7	50.6	395.9	53.1	410.9
May	58.1	499.8	54.4	618.5	60.0	485.2	61.1	475.7	63.4	506.0
Jun	65.0	546.5	61.8	672.6	70.5	544.4	70.8	534.2	72.9	568.7
Jul	73.4	633.6	71.5	705.2	74.7	527.2	74.5	525.8	76.1	558.3
Aug	71.5	523.9	69.5	607.4	73.7	466.4	72.9	465.1	74.4	489.8
Sep	63.3	389.1	59.4	479.9	65.9	367.2	64.6	368.1	67.2	394.4
Oct	51.8	233.2	48.4	326.4	55.4	262.8	54.4	270.1	56.6	289.8
Nov	40.5	112.0	35.7	186.8	40.4	153.4	39.2	161.3	41.9	183.5
Dec	34.8	77.6	26.9	129.4	28.5	108.9	26.6	117.4	30.5	132.9
Ann	51.7	328.2	46.7	414.8	50.6	329.6	49.8	331.9	52.7	353.0

STATE:	Indiana		Indiana		Indiana		Indiana		Kansas	
STATION:	Evansville		Ft. Wayne		Indianapolis		South Bend		Dodge City	
LATITUDE:	3803N		4100N		4142N		4142N		3746N	
LONGITUDE:	8732W		8512W		8619W		8619W		9958W	
ELEVATION:	118		252		236		236		787	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	32.6	155.7	25.3	123.5	27.9	134.4	24.0	112.8	30.8	224.2
Feb	35.9	223.3	27.6	189.2	30.7	202.6	26.3	178.9	35.2	304.3
Mar	44.3	312.2	36.5	266.4	39.7	281.4	35.3	269.2	41.2	400.5
Apr	56.7	407.1	49.3	369.1	52.3	379.3	48.1	376.3	54.0	511.5
May	65.7	483.6	59.6	453.5	62.2	457.9	58.4	467.2	64.0	566.8
Jun	74.7	537.8	69.5	499.5	71.7	506.7	68.6	521.3	73.7	639.7
Jul	77.8	520.9	73.0	484.7	75.0	490.0	72.3	502.5	79.2	622.6
Aug	76.2	470.6	71.3	432.5	73.2	445.8	71.0	452.0	78.1	557.5
Sep	69.1	380.6	64.5	345.5	66.3	359.1	63.8	350.3	68.9	457.5
Oct	58.2	294.8	53.6	250.7	55.7	265.0	53.4	246.6	57.9	352.8
Nov	44.9	185.1	40.2	140.1	41.7	157.1	39.6	134.8	42.8	242.4
Dec	35.3	135.3	28.6	100.2	30.9	113.0	28.2	92.3	33.4	198.5
Ann	56.0	342.3	49.9	304.5	52.3	316.0	49.1	308.7	54.9	423.2

STATE:	Kansas		Kansas		Kansas		Kentucky		Kentucky	
STATION:	Goodland		Topeka		Wichita		Lexington		Louisville	
LATITUDE:	3922N		3904N		3739N		3802N		3811N	
LONGITUDE:	10142W		9538W		9725W		8436W		8544W	
ELEVATION:	1124		270		408		301		149	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	27.6	214.1	28.0	184.7	31.3	212.6	32.9	148.1	33.3	148.0
Feb	31.5	286.4	33.4	255.2	36.3	287.0	35.3	211.4	35.8	214.1
Mar	36.3	386.2	41.2	340.9	43.6	381.2	43.6	298.2	44.0	298.9
Apr	48.7	496.2	54.5	445.3	56.6	483.5	55.3	401.2	55.9	397.8
May	58.9	559.2	64.5	519.6	66.1	552.2	64.7	473.9	64.8	466.5
Jun	69.1	639.2	73.5	576.8	75.8	614.2	73.0	514.6	73.3	516.3
Jul	75.8	629.2	78.2	577.2	80.7	607.2	76.2	501.9	76.9	498.4
Aug	74.1	554.2	77.2	518.1	79.7	551.1	75.0	457.1	75.9	455.8
Sep	64.3	445.5	68.2	411.3	70.6	438.4	68.6	369.5	69.1	369.2
Oct	52.8	344.0	57.6	311.0	59.6	339.0	57.8	283.2	58.1	282.7
Nov	38.5	232.3	42.9	209.3	44.8	236.2	44.6	178.3	45.0	177.1
Dec	30.1	188.4	31.8	158.3	34.5	187.1	35.5	131.7	35.6	132.3
Ann	50.6	414.6	54.3	375.6	56.6	407.5	55.2	330.8	55.6	329.8

STATE:	Louisiana		Louisiana		Louisiana		Louisiana		Massachusetts	
STATION:	Baton Rouge		Lake Charles		New Orleans		Shreveport		Boston	
LATITUDE:	3032N		3007N		2959N		3228N		4222N	
LONGITUDE:	9109W		9313W		9015W		9349W		7102W	
ELEVATION:	23		3		3		79		5	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	51.0	213.0	52.3	197.6	52.9	226.4	47.2	206.8	29.2	129.0
Feb	53.9	285.9	55.1	273.9	55.6	301.6	50.5	281.7	30.4	192.5
Mar	59.7	374.2	60.3	356.3	60.7	383.7	56.8	363.9	38.1	275.7
Apr	68.4	456.0	68.9	426.0	68.6	482.9	66.4	437.5	48.6	359.6
May	74.8	507.6	75.2	501.6	75.1	533.7	73.4	511.6	58.6	439.6
Jun	80.3	522.5	80.7	534.4	80.4	543.5	80.2	560.1	68.0	492.9
Jul	82.0	473.5	82.4	484.9	81.9	491.9	83.2	546.3	73.3	474.5
Aug	81.6	454.8	82.2	449.6	81.9	465.6	83.2	509.2	71.3	403.2
Sep	77.5	397.2	78.4	402.8	78.2	410.6	77.4	421.5	64.5	341.7
Oct	68.5	352.9	70.0	374.6	69.8	362.1	67.5	353.6	55.4	241.3
Nov	58.6	249.6	60.2	248.6	60.1	263.8	56.2	251.9	45.2	136.4
Dec	52.9	199.9	54.3	191.4	54.8	211.4	49.2	198.2	33.0	109.3
Ann	67.4	373.9	68.3	370.1	68.3	389.8	65.9	386.8	51.3	299.6

STATE:	Maryland		Maryland		Maine		Maine		Maine	
STATION:	Baltimore		Patuxent R.		Bangor		Caribou		Portland	
LATITUDE:	3911N		3817N		4448N		4652N		4339N	
LONGITUDE:	7640W		7625W		6849W		6801W		7019W	
ELEVATION:	47		14		62		190		19	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	33.4	159.2	0.0	165.0	0.0	123.3	10.7	113.7	21.5	122.1
Feb	34.8	227.8	0.0	233.8	0.0	196.8	12.9	196.4	22.9	185.0
Mar	42.8	315.2	0.0	320.4	0.0	296.7	23.6	307.4	31.8	263.0
Apr	53.8	403.6	0.0	417.2	0.0	390.7	36.7	383.6	42.7	353.7
May	63.7	464.9	0.0	478.2	0.0	469.0	49.7	428.0	52.7	425.1
Jun	72.4	509.7	0.0	513.5	0.0	503.7	59.6	476.7	62.2	464.3
Jul	76.6	494.5	0.0	492.8	0.0	504.3	64.9	478.0	68.0	450.0
Aug	74.9	433.9	0.0	441.3	0.0	437.1	62.3	407.1	66.4	396.3
Sep	68.5	360.8	0.0	368.1	0.0	340.3	54.1	299.1	58.7	314.1
Oct	57.4	270.6	0.0	276.9	0.0	227.5	43.8	186.7	49.1	223.1
Nov	46.1	179.1	0.0	191.7	0.0	127.8	31.4	99.4	38.6	124.6
Dec	35.3	135.4	0.0	145.6	0.0	102.7	16.1	84.2	25.7	98.4
Ann	55.0	329.6	0.0	337.0	0.0	310.0	38.8	288.4	45.0	285.0

STATE:	Michigan		Michigan		Michigan		Michigan		Michigan	
STATION:	Alpena		Detroit		Flint		Grand Rapids		Houghton	
LATITUDE:	4504N		4225N		4258N		4253N		4710N	
LONGITUDE:	8334W		8301W		8344W		8531W		8330W	
ELEVATION:	210		191		233		245		329	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	17.8	98.2	25.5	113.2	22.3	103.9	23.2	100.2	0.0	66.3
Feb	18.3	167.3	26.9	184.6	23.8	172.6	24.5	175.8	0.0	131.3
Mar	26.2	278.9	35.4	271.3	32.6	259.5	33.1	275.1	0.0	253.2
Apr	40.1	381.7	48.1	379.5	45.9	363.2	46.5	383.0	0.0	370.6
May	50.5	466.6	58.4	465.4	55.8	449.8	57.1	476.1	0.0	450.3
Jun	60.9	509.7	69.1	506.2	65.8	491.8	67.4	530.7	0.0	498.5
Jul	65.5	511.2	73.3	497.8	69.7	487.4	71.5	519.3	0.0	498.5
Aug	64.2	429.5	71.9	427.3	68.2	421.8	70.0	454.7	0.0	412.7
Sep	56.3	313.6	64.5	339.9	61.0	324.3	62.4	342.4	0.0	274.0
Oct	47.3	201.6	54.3	237.6	51.2	224.8	52.0	232.7	0.0	181.9
Nov	34.9	103.6	41.1	129.6	38.3	116.4	38.7	120.9	0.0	78.9
Dec	23.4	73.4	29.6	93.2	26.8	83.8	27.4	84.3	0.0	52.0
Ann	42.1	294.6	49.9	303.8	46.8	291.6	47.8	307.9	0.0	272.3

STATE:	Michigan		Michigan		Minnesota		Minnesota		Minnesota	
STATION:	Sault Ste. M.		Traverse City		Duluth		Int'l. Falls		Minn/St.Paul	
LATITUDE:	4628N		4444N		4650N		4834N		4453N	
LONGITUDE:	8422W		8535W		9211W		9323W		931[illegible]W	
ELEVATION:	221		192		432		361		255	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	14.2	88.1	20.8	84.3	8.5	105.4	1.9	96.5	12.2	125.9
Feb	15.2	163.6	20.7	153.9	12.1	182.5	7.0	179.7	16.5	207.2
Mar	24.0	279.0	28.7	271.5	23.5	280.6	20.6	283.7	28.3	299.3
Apr	38.2	375.2	42.7	381.2	38.6	372.4	38.2	391.6	45.1	391.1
May	49.0	457.9	52.8	469.0	49.4	445.6	50.1	465.5	57.1	471.2
Jun	58.7	491.2	63.7	518.7	59.0	479.3	60.4	502.7	66.9	522.8
Jul	63.8	497.8	68.7	518.0	65.6	503.0	65.8	521.1	71.9	534.3
Aug	63.2	413.0	67.5	436.5	64.1	419.6	63.2	439.0	70.2	457.6
Sep	55.3	284.6	59.4	316.1	54.4	297.0	53.0	304.1	60.0	340.3
Oct	46.2	182.6	49.8	204.5	45.3	196.6	43.5	190.9	50.0	233.2
Nov	32.8	90.0	36.9	102.2	28.4	103.3	24.9	93.7	32.4	130.3
Dec	20.1	68.6	25.9	69.6	14.4	79.1	8.7	73.7	18.6	95.8
Ann	40.0	282.6	44.8	293.8	38.6	288.7	36.5	295.2	44.1	317.4

STATE:	Minnesota		Missouri		Missouri		Missouri		Missouri	
STATION:	Rochester		Columbia		Kansas City		Springfield		St. Louis	
LATITUDE:	4355N		3849N		3918N		3714N		3845N	
LONGITUDE:	9230W		9213W		9443W		9323W		9023W	
ELEVATION:	402		270		315		387		172	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	12.9	129.4	29.3	165.9	27.1	175.7	32.9	185.4	31.3	170.2
Feb	16.9	204.2	33.6	237.3	32.3	242.7	37.0	251.1	35.1	240.2
Mar	27.8	293.5	41.7	319.7	40.7	326.3	44.0	335.0	43.3	326.8
Apr	44.5	382.4	55.0	413.9	54.2	427.2	56.5	435.2	56.5	424.3
May	56.2	459.9	64.4	509.9	64.1	507.9	65.1	510.4	65.8	507.6
Jun	66.0	515.9	73.0	566.8	73.0	564.1	73.6	562.9	74.9	567.6
Jul	70.1	517.8	77.3	574.0	77.5	570.2	77.8	559.6	78.6	555.9
Aug	68.6	450.9	76.0	509.4	76.5	505.2	77.1	508.2	77.2	492.7
Sep	59.3	339.1	68.3	393.4	68.0	394.0	69.3	401.6	69.6	395.8
Oct	49.6	235.9	58.0	298.6	57.6	296.3	59.0	310.3	59.1	298.3
Nov	32.6	134.1	43.9	190.6	42.3	200.0	45.5	210.3	45.0	194.8
Dec	18.9	100.4	32.8	141.7	31.3	152.3	36.0	163.5	34.6	143.9
Ann	43.6	313.6	54.4	360.1	53.7	363.5	56.1	369.5	55.9	359.8

STATE:	Mississippi		Mississippi		Montana		Montana		Montana	
STATION:	Jackson		Meridian		Billings		Cut Bank		Dillon	
LATITUDE:	3219N		3220N		4548N		4836N		4515N	
LONGITUDE:	9005W		8845W		10832W		11222W		11233W	
ELEVATION:	101		94		1088		1170		1588	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	47.1	204.4	46.9	201.8	21.9	131.8	16.2	10-9.1	20.2	142.8
Feb	49.8	278.4	49.8	274.6	27.4	207.0	22.4	186.6	25.5	229.5
Mar	56.1	371.4	56.1	360.2	32.6	322.6	26.8	306.0	29.6	347.0
Apr	65.7	463.4	65.4	450.7	44.6	414.0	39.5	402.7	41.1	444.6
May	72.7	526.4	72.4	504.4	54.5	518.8	49.6	510.6	50.4	539.6
Jun	79.4	549.1	79.2	532.4	62.6	589.6	56.5	554.8	57.5	581.4
Jul	81.7	517.8	81.2	494.6	71.8	646.6	64.4	620.3	66.4	648.8
Aug	81.2	483.0	80.7	471.8	70.1	548.6	62.6	514.4	64.6	548.8
Sep	76.0	409.4	75.3	394.4	58.9	398.7	53.2	366.7	54.7	412.6
Oct	65.8	344.9	64.8	341.1	49.3	267.7	44.1	236.3	45.0	277.6
Nov	55.3	244.6	54.2	243.2	35.7	152.3	29.7	130.3	31.8	163.3
Dec	48.9	192.3	47.9	189.7	26.8	114.2	21.4	90.7	23.9	122.1
Ann	65.0	382.1	64.9	371.6	46.3	359.3	40.5	335.7	42.6	371.5

STATE:	Montana		Montana		Montana		Montana		Montana	
STATION:	Glasgow		Great Falls		Helena		Lewiston		Miles City	
LATITUDE:	4813N		4729N		4636N		4703N		4626N	
LONGITUDE:	10537W		11122W		11200W		10927W		10552W	
ELEVATION:	700		1116		1188		1264		803	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	9.2	105.2	20.5	114.1	18.1	113.8	19.1	113.9	15.4	124.0
Feb	15.2	182.1	26.6	195.3	25.4	192.3	23.8	187.8	21.6	202.2
Mar	25.2	299.7	30.5	317.5	30.6	310.7	27.5	306.1	30.2	321.4
Apr	42.8	403.6	43.4	403.8	42.7	403.3	40.1	391.8	45.3	418.3
May	54.2	495.8	53.3	501.1	52.2	504.6	49.6	490.2	56.3	514.2
Jun	62.0	555.3	60.8	570.0	59.2	553.3	56.6	558.5	64.9	582.1
Jul	70.5	594.8	69.3	631.7	67.9	633.0	65.5	620.6	74.4	621.9
Aug	69.0	505.3	67.4	524.3	66.2	523.6	64.4	515.8	72.5	536.3
Sep	57.2	363.6	57.3	373.9	55.5	383.1	54.0	372.2	59.9	391.6
Oct	46.4	238.0	48.3	250.8	45.3	251.2	45.5	245.5	48.8	260.6
Nov	29.0	129.9	34.6	135.0	31.7	141.4	32.2	136.3	32.4	149.5
Dec	17.1	90.7	26.5	91.2	23.3	98.8	24.5	98.5	22.0	108.3
Ann	41.5	330.3	44.9	342.4	43.2	342.4	41.9	336.4	45.3	352.5

STATE:	Montana		North Carolina		North Carolina		North Carolina		North Carolina	
STATION:	Missoula		Asheville		Cape Hatteras		Charlotte		Cherry Point	
LATITUDE:	4655N		3526N		3516N		3513N		3454N	
LONGITUDE:	11405W		8232W		7533W		8056W		7653W	
ELEVATION:	972		661		2		234		11	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	20.8	84.6	37.9	195.7	45.3	186.0	42.1	295.0	0.0	205.3
Feb	27.2	155.7	39.4	263.5	45.8	258.3	44.0	263.4	0.0	278.1
Mar	33.3	266.2	45.9	354.3	50.6	359.8	50.6	357.4	0.0	376.1
Apr	43.9	374.9	55.9	452.3	58.9	481.2	60.8	459.8	0.0	486.6
May	52.5	483.5	63.7	489.4	67.0	532.1	68.8	503.3	0.0	522.1
Jun	58.9	524.3	70.6	503.0	74.3	552.2	75.9	521.1	0.0	525.9
Jul	66.6	631.3	73.5	481.8	78.0	521.0	78.5	496.6	0.0	496.3
Aug	65.0	510.2	72.8	441.2	77.5	462.6	77.7	459.8	0.0	443.3
Sep	55.3	368.3	66.7	369.1	73.7	398.9	72.0	384.0	0.0	387.1
Oct	44.1	[illegible]	56.8	311.2	65.2	308.3	61.7	318.3	0.0	317.3
Nov	32.3	111.3	46.3	230.2	56.0	236.8	51.0	234.8	0.0	245.9
Dec	24.7	72.5	38.7	178.4	47.7	178.7	42.5	182.4	0.0	194.7
Ann	43.7	316.9	55.7	355.9	61.7	373.0	60.5	364.7	0.0	373.2

STATE:	North Carolina		North Carolina		North Dakota		North Dakota		North Dakota	
STATION:	Greensboro		Raleigh		Bismarck		Fargo		Minot	
LATITUDE:	3605N		3552N		4646N		4654N		4816N	
LONGITUDE:	7957W		7847W		10045W		9648W		10117W	
ELEVATION:	270		134		502		274		522	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	38.7	194.0	40.5	188.2	8.2	126.6	5.9	112.5	7.9	104.1
Feb	40.6	263.1	42.2	255.8	13.5	210.4	10.7	191.4	12.8	177.9
Mar	47.8	356.2	49.2	346.0	25.1	316.8	24.2	297.8	23.6	283.3
Apr	58.6	456.6	59.5	446.0	43.0	395.8	42.3	400.3	41.1	396.2
May	67.1	506.7	67.4	490.5	54.4	501.3	54.6	497.7	52.8	500.8
Jun	74.4	529.8	74.4	505.6	63.8	558.7	64.7	540.8	62.0	535.7
Jul	77.2	505.5	77.5	481.6	70.8	592.3	70.7	575.0	68.8	569.0
Aug	76.0	460.2	76.5	437.1	69.2	509.0	69.2	495.1	67.2	480.4
Sep	69.7	384.5	70.6	373.5	57.5	367.4	57.9	353.6	56.2	346.4
Oct	59.2	309.6	60.2	299.8	46.8	246.2	47.0	237.0	46.1	230.4
Nov	48.3	227.6	50.0	220.3	28.9	137.6	28.6	124.0	27.9	118.9
Dec	39.6	178.7	41.2	172.4	15.6	101.1	13.0	91.5	14.7	84.1
Ann	58.1	364.4	59.1	351.4	41.4	338.6	40.8	326.4	40.1	319.6

STATE:	Nebraska		Nebraska		Nebraska		Nebraska		NHampshire	
STATION:	Grand Island		North Omaha		North Platte		Scottsbluff		Concord	
LATITUDE:	4058N		4122N		4108N		4152N		4312N	
LONGITUDE:	9819W		9601W		10041W		10336W		7130W	
ELEVATION:	566		404		849		1206		105	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	22.3	179.4	20.2	172.0	23.4	187.8	24.9	183.3	20.6	124.6
Feb	27.7	248.7	25.5	242.0	28.1	259.9	29.5	257.8	22.6	186.1
Mar	35.5	343.2	34.6	331.6	34.3	361.6	34.3	354.6	32.3	264.1
Apr	49.9	459.1	50.0	422.7	47.8	467.6	46.2	452.4	44.2	357.3
May	60.7	534.8	60.9	507.9	58.3	539.1	56.5	524.4	55.1	429.2
Jun	70.7	608.2	70.2	575.7	68.0	614.8	65.9	606.7	64.7	462.4
Jul	76.3	601.0	75.1	571.4	74.3	617.7	73.7	619.5	69.7	454.2
Aug	75.0	526.1	73.7	504.1	73.0	539.7	71.6	542.4	67.2	394.7
Sep	64.4	409.4	64.4	372.5	62.3	424.6	61.2	433.7	59.5	309.3
Oct	53.7	308.6	54.4	284.8	51.0	319.3	50.2	310.6	49.3	221.6
Nov	38.2	200.3	37.9	174.7	36.2	206.0	36.2	196.2	38.0	125.5
Dec	27.0	154.4	25.7	138.7	26.8	164.2	27.6	156.0	24.8	98.2
Ann	50.1	381.1	49.4	358.2	48.6	391.8	48.2	386.4	45.6	285.6

STATE:	New Jersey		New Jersey		New Mexico		New Mexico		New Mexico	
STATION:	Lakehurst		Newark		Albuquerque		Clayton		Farrington	
LATITUDE:	4002N		4042N		3503N		3627N		3645N	
LONGITUDE:	7420W		7410W		10637W		10309W		10814W	
ELEVATION:	37		9		1619		1515		1677	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	0.0	151.8	31.4	149.5	35.2	275.7	33.1	260.8	28.6	256.2
Feb	0.0	216.2	32.6	215.1	40.0	364.0	36.1	336.5	35.0	347.4
Mar	0.0	300.6	40.6	300.7	45.8	479.4	40.4	448.0	40.6	459.3
Apr	0.0	394.9	51.7	392.9	55.8	604.4	50.8	553.2	49.7	578.5
May	0.0	453.5	70.9	457.6	65.3	688.5	60.0	602.7	59.5	665.0
Jun	0.0	481.4	61.9	487.0	74.6	726.6	69.2	655.8	67.9	723.0
Jul	0.0	462.0	71.4	477.4	73.6	675.0	73.6	619.4	75.0	672.2
Aug	0.0	415.8	76.4	424.5	72.4	621.2	72.4	568.9	72.6	610.9
Sep	0.0	341.9	74.6	345.3	65.0	534.8	65.0	488.8	64.6	524.7
Oct	0.0	259.2	67.8	257.9	54.8	419.5	54.8	388.8	52.9	401.1
Nov	0.0	168.5	57.5	161.7	42.3	307.5	42.3	278.8	39.2	284.1
Dec	0.0	128.8	46.2	123.3	35.1	251.6	35.1	233.4	30.1	227.1
Ann	0.0	314.6	34.5	316.1	52.7	495.7	52.7	452.9	51.3	479.1

STATE:	New Mexico		New Mexico		New Mexico		New Mexico		Nevada	
STATION:	Roswell		Truth or Con.		Tucumcari		Zuni		Elko	
LATITUDE:	3324N		3314N		3511N		3506N		4050N	
LONGITUDE:	10432W		10716W		10336W		10848W		11547W	
ELEVATION:	1103		1481		1231		1965		1547	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	38.1	283.9	40.0	303.2	37.0	273.6	30.3	267.5	23.2	186.9
Feb	42.9	372.3	44.9	393.7	41.1	351.7	34.6	351.9	29.2	280.6
Mar	49.3	490.2	50.2	511.7	46.7	464.5	39.6	457.7	35.0	396.8
Apr	59.7	601.5	59.5	634.1	56.9	569.2	48.1	587.8	43.5	515.3
May	68.5	667.0	59.5	693.5	65.6	627.6	56.6	670.8	51.9	624.8
Jun	77.0	708.0	76.9	718.7	75.1	673.8	65.4	705.8	59.6	687.3
Jul	79.2	662.0	79.3	641.4	78.4	637.2	71.4	614.2	69.5	711.4
Aug	77.9	608.1	77.4	601.1	76.7	587.0	69.4	563.7	67.0	628.2
Sep	70.4	518.9	71.6	526.3	69.6	496.2	63.3	514.0	57.6	513.4
Oct	59.6	414.2	61.3	428.2	58.7	391.4	51.5	405.9	46.9	358.7
Nov	46.9	306.9	48.7	330.0	46.2	291.0	40.1	295.2	34.8	220.3
Dec	39.3	258.2	40.8	271.9	38.6	246.8	32.0	242.1	25.9	167.4
Ann	59.1	490.9	59.9	504.5	57.6	467.5	50.3	473.0	45.4	440.9

STATE:	Nevada		Nevada		Nevada		Nevada		Nevada	
STATION:	Ely		Las Vegas		Lovelock		Reno		Tonopak	
LATITUDE:	3977N		3605N		4004N		3930N		3804N	
LONGITUDE:	11451W		11510W		11833W		11947W		11708W	
ELEVATION:	1906		664		1190		1341		1653	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	23.6	222.3	265.3	44.2	28.9	218.1	31.9	217.1	30.2	249.0
Feb	27.9	309.5	363.3	49.1	35.2	316.1	37.1	311.9	34.6	345.6
Mar	32.8	435.6	494.6	54.8	40.1	449.3	40.3	447.4	39.6	482.0
Apr	41.3	544.9	629.0	63.8	48.5	587.3	46.8	585.7	48.1	610.5
May	50.0	626.8	717.8	73.3	57.5	692.9	54.6	684.4	56.9	699.1
Jun	57.7	681.6	753.5	82.3	65.6	745.8	61.5	732.7	65.3	756.2
Jul	67.2	663.8	702.1	89.6	14.3	755.1	69.3	730.2	73.0	733.1
Aug	65.5	605.0	638.7	87.4	71.3	673.8	66.9	652.5	70.7	661.3
Sep	56.7	524.9	552.6	80.1	62.7	549.9	60.2	541.9	63.5	554.1
Oct	46.0	381.[illegible]	417.7	67.1	51.2	393.6	50.3	388.1	52.1	412.4
Nov	34.0	251.3	294.4	53.3	38.4	252.1	40.1	247.5	39.8	279.6
Dec	26.2	196.0	238.8	45.2	30.8	193.8	33.0	191.4	31.9	224.3
Ann	44.1	453.6	505.7	65.8	50.4	485.7	49.4	477.6	50.5	500.6

STATE:	Nevada		Nevada		New York		New York		New York	
STATION:	Winnemucca		Yucca Flats		Albany		Binghamton		Buffalo	
LATITUDE:	4045N		3657N		4245N		4213N		4256N	
LONGITUDE:	11748W		11603W		7348W		7599W		7844W	
ELEVATION:	1323		1197		89		499		215	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	28.2	187.3	0.0	258.6	21.5	123.8	22.0	104.6	23.7	94.6
Feb	34.1	278.7	0.0	345.4	23.5	186.7	22.8	156.2	24.4	148.2
Mar	37.6	399.3	0.0	478.5	33.4	267.4	31.3	233.6	32.1	241.0
Apr	45.1	533.7	0.0	609.3	46.9	362.2	44.7	336.8	44.9	356.7
May	53.8	640.6	0.0	699.0	57.7	425.8	55.1	405.8	55.1	433.1
Jun	61.7	696.9	0.0	741.5	67.5	469.2	64.8	456.1	65.7	489.2
Jul	71.0	726.3	0.0	719.7	72.0	467.9	69.1	450.0	70.1	481.8
Aug	67.8	636.9	0.0	646.1	69.6	406.6	67.3	386.4	68.4	410.4
Sep	59.2	517.3	0.0	548.4	61.9	317.4	60.2	306.8	61.6	312.4
Oct	48.3	358.6	0.0	411.3	51.4	221.7	50.3	211.4	51.5	212.8
Nov	37.3	219.6	0.0	282.5	39.6	124.0	38.2	112.2	39.8	109.4
Dec	30.4	167.7	0.0	231.3	25.9	96.5	25.4	80.6	27.9	76.8
Ann	47.9	446.9	0.0	497.6	47.6	289.1	46.0	270.1	47.1	280.5

STATE:	New York		New York		New York		New York		New York	
STATION:	Massena		Central Park		La Guardia		Rochester		Syracuse	
LATITUDE:	4456N		4047N		4046N		4307N		4307N	
LONGITUDE:	7451W		7358W		7354W		7740W		7607W	
ELEVATION:	63		57		16		169		124	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	14.5	106.1	32.2	135.7	32.1	148.5	24.0	98.8	23.6	104.4
Feb	16.7	168.2	33.4	195.6	33.1	215.5	24.8	151.8	24.6	155.0
Mar	27.6	265.2	41.1	281.3	40.6	303.1	33.0	245.1	33.2	241.5
Apr	42.2	364.3	52.1	370.0	51.7	395.1	46.1	363.2	46.5	359.1
May	54.1	437.6	62.3	443.8	61.8	458.5	56.5	435.7	56.8	428.0
Jun	64.3	482.5	71.6	463.9	71.5	488.8	66.9	492.8	66.9	482.2
Jul	64.3	474.9	76.6	457.8	76.7	483.9	71.2	483.0	71.5	476.8
Aug	66.7	402.5	74.9	402.3	74.9	429.4	69.3	412.0	69.7	407.8
Sep	59.2	304.8	68.4	329.2	68.1	347.2	62.3	314.6	62.8	316.1
Oct	48.5	199.7	58.7	242.9	58.1	257.8	52.3	212.1	52.5	210.9
Nov	35.9	105.2	47.4	144.6	47.3	160.9	40.5	109.6	41.0	108.2
Dec	20.1	79.8	35.5	109.6	35.6	123.9	28.3	76.2	28.1	77.4
Ann	43.2	282.6	54.5	298.1	54.3	317.7	47.9	282.9	48.1	280.6

STATE:	Ohio		Ohio		Ohio		Ohio		Ohio	
STATION:	Akron-Canton		Cincinnati		Cleveland		Columbus		Dayton	
LATITUDE:	4055N		3904N		4124N		4000N		3954N	
LONGITUDE:	8126W		8440W		8151W		8253W		8413W	
ELEVATION:	377		271		245		254		306	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	26.3	116.2	32.2	135.8	26.9	105.4	28.4	124.6	28.1	132.7
Feb	27.7	176.2	33.4	200.3	27.9	163.0	30.3	183.6	30.4	196.7
Mar	36.2	261.5	41.1	278.7	36.1	250.2	39.2	265.7	39.0	278.1
Apr	48.5	368.1	52.1	379.3	48.3	366.0	51.2	367.0	51.4	380.6
May	58.7	452.4	62.3	453.6	58.3	456.0	61.1	446.7	61.6	460.9
Jun	68.3	498.9	72.1	498.3	67.9	500.0	70.4	491.7	71.3	508.2
Jul	71.7	484.7	75.6	480.4	71.4	495.8	73.6	476.0	74.6	490.8
Aug	70.3	402.5	74.4	443.3	70.0	429.3	71.9	445.0	73.0	446.3
Sep	63.7	304.8	67.8	355.8	63.9	336.2	65.2	347.6	66.3	357.5
Oct	53.3	199.7	56.8	268.5	53.8	235.2	54.2	256.4	55.5	262.8
Nov	40.7	105.2	43.8	159.6	41.6	126.4	41.7	145.9	41.8	153.0
Dec	29.4	579.8	33.7	117.3	30.3	86.2	30.7	105.0	30.9	110.5
Ann	49.6	282.6	54.0	314.2	49.7	295.8	51.5	304.6	52.0	314.9

STATE:	Ohio		Ohio		Oklahoma		Oklahoma		Oregon	
STATION:	Toledo		Youngstown		Oklahoma City		Tulsa		Astoria	
LATITUDE:	4136N		4116N		3524N		3612N		4609N	
LONGITUDE:	8348W		8040W		9736W		9554W		1235W	
ELEVATION:	211		361		397		206		7	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	24.8	117.9	25.7	104.4	36.8	217.2	36.6	198.5	40.6	85.4
Feb	27.1	184.6	26.7	159.1	41.3	286.2	41.2	265.3	43.6	147.9
Mar	35.8	270.3	35.3	241.4	48.2	379.8	48.3	354.1	44.4	234.9
Apr	48.4	375.4	47.7	346.7	60.4	468.0	60.8	434.7	47.8	339.9
May	58.8	465.7	57.6	430.2	68.3	520.3	68.8	494.3	52.3	436.2
Jun	68.9	509.5	67.0	477.2	76.8	581.5	77.3	548.1	56.5	441.0
Jul	72.3	501.6	70.7	470.3	81.5	577.3	82.1	550.8	60.0	473.7
Aug	70.8	438.3	69.2	408.6	81.1	529.0	81.4	506.0	60.3	406.5
Sep	63.8	346.0	62.7	323.8	73.0	421.6	73.3	399.5	58.4	320.9
Oct	53.0	247.1	52.6	230.9	62.4	344.3	62.9	315.7	52.8	193.4
Nov	39.6	135.0	40.3	123.8	49.2	244.4	49.4	224.4	46.5	105.0
Dec	28.0	96.4	28.8	85.5	40.0	196.8	39.8	178.8	42.8	70.7
Ann	49.3	307.3	48.7	283.5	59.9	396.4	60.2	372.5	50.5	271.3

STATE:	Oregon		Oregon		Oregon		Oregon		Oregon	
STATION:	Burns		Medford		North Bend		Pendleton		Portland	
LATITUDE:	4335N		4222N		4325N		4541N		4536N	
LONGITUDE:	11903W		12252W		12415W		11851W		12236W	
ELEVATION:	1271		396		5		456		12	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	25.2	132.9	36.3	110.4	44.6	119.0	32.0	94.4	38.1	84.1
Feb	31.0	214.8	41.3	200.0	46.6	191.1	38.9	166.4	42.8	150.3
Mar	36.1	322.0	44.8	307.2	46.9	287.0	43.8	283.1	45.7	242.8
Apr	44.2	447.2	50.2	444.5	49.1	409.5	50.9	407.6	50.6	354.7
May	52.2	556.7	57.3	551.6	53.1	503.7	58.5	522.3	56.7	451.1
Jun	59.0	618.4	64.3	617.9	56.9	540.8	65.6	581.6	62.0	480.8
Jul	68.4	667.3	71.7	671.4	59.0	571.7	73.5	649.8	67.1	552.6
Aug	66.1	564.9	70.4	575.2	59.7	484.4	71.5	540.9	66.6	454.0
Sep	58.2	439.4	64.4	431.0	58.4	373.6	64.0	407.5	62.2	330.0
Oct	47.3	282.8	53.4	266.3	54.9	242.1	52.6	246.3	53.8	196.3
Nov	35.8	161.0	43.3	136.8	50.1	142.3	41.4	118.9	45.3	105.1
Dec	27.9	116.8	37.7	91.3	46.5	103.3	35.7	79.5	40.7	70.5
Ann	46.0	377.0	53.0	367.0	52.2	330.7	52.4	341.5	52.6	289.4

STATE:	Oregon		Oregon		Pennsylvania		Pennsylvania		Pennsylvania	
STATION:	Redmond		Salem		Allentown		Erie		Harrisburg	
LATITUDE:	4416N		4455N		4039N		4205N		4013N	
LONGITUDE:	12109W		12301W		7526W		8011W		7651W	
ELEVATION:	940		61		117		225		106	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	30.2	133.2	38.8	90.1	27.8	143.1	25.1	93.7	30.1	145.3
Feb	35.8	210.2	42.9	159.5	29.4	207.1	25.2	156.5	32.3	209.1
Mar	38.6	322.8	45.2	256.9	38.1	292.5	32.9	249.6	41.0	293.8
Apr	38.6	456.5	49.8	371.7	49.9	382.4	44.8	368.6	52.8	382.6
May	51.3	564.1	55.7	471.4	60.1	444.0	54.6	446.6	63.1	448.2
Jun	58.2	620.4	61.2	501.4	69.5	482.0	64.6	500.9	72.0	498.5
Jul	65.7	663.5	66.6	581.1	74.1	478.7	68.7	497.1	76.1	478.4
Aug	63.8	561.1	66.1	481.4	71.7	419.4	67.5	394.6	73.9	420.6
Sep	57.7	429.7	61.9	360.3	64.7	335.8	61.4	315.8	67.0	343.5
Oct	48.4	271.1	53.2	208.7	54.1	251.2	51.6	224.4	55.8	253.4
Nov	39.0	155.2	45.2	111.3	42.3	154.1	40.1	112.9	43.8	157.0
Dec	33.4	115.2	40.9	75.2	30.7	116.8	29.1	75.3	32.6	121.3
Ann	47.2	375.2	52.3	305.8	51.0	308.9	47.1	287.2	53.4	311.9

STATE:	Pennsylvania		Pennsylvania		Pennsylvania		Pacific Is.		Pacific Is.	
STATION:	Philadelphia		Pittsburg		Wilkes-Barre		Koror Is.		Kwajalein Is.	
LATITUDE:	3953N		4030N		4120N		720N		844	
LONGITUDE:	75159W		80131W		7544W		13429E		16744E	
ELEVATION:	9		373		289		33		8	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	32.3	150.6	28.1	115.1	26.0	123.4	81.2	378.9	81.2	426.9
Feb	33.9	215.5	29.3	169.6	27.3	186.8	80.7	422.8	81.4	475.2
Mar	41.9	300.6	38.1	255.7	36.0	268.9	81.1	442.4	81.7	487.2
Apr	52.9	388.9	50.2	357.1	48.5	363.2	81.9	458.9	81.8	472.1
May	63.2	450.2	59.8	434.5	58.9	431.5	82.0	425.2	81.8	441.3
Jun	72.3	491.3	68.6	477.8	67.9	477.4	81.6	394.8	81.9	436.8
Jul	76.8	476.9	71.9	458.2	72.2	473.5	81.1	391.2	82.1	436.6
Aug	74.8	427.1	70.2	409.7	70.0	410.5	81.2	402.2	82.5	457.6
Sep	68.1	347.6	63.8	327.9	62.9	325.2	81.6	414.1	82.5	438.2
Oct	57.4	260.0	53.2	242.8	52.6	243.2	81.9	408.7	82.4	413.7
Nov	46.2	168.0	41.3	136.9	40.8	132.8	81.9	393.0	81.7	395.6
Dec	35.2	127.6	30.5	94.1	29.1	99.8	81.3	363.1	81.6	393.4
Ann	54.6	317.0	50.4	289.9	49.4	294.7	81.5	407.9	81.9	439.6

STATE:	Pacific Is.		Puerto Rico		Rhode Island		S.Carolina		S.Carolina	
STATION:	Wake Is.		San Juan		Providence		Charleston		Columbia	
LATITUDE:	1917N		1826N		4144N		3254N		3357N	
LONGITUDE:	16639E		6600W		7126W		8002W		8107N	
ELEVATION:	4		19		19		12		69	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	77.0	366.0	75.4	359.6	28.4	137.3	48.6	201.9	45.4	206.6
Feb	77.0	426.4	75.3	416.6	29.4	200.3	50.5	270.0	47.6	276.8
Mar	77.7	491.3	76.3	485.0	36.9	279.9	56.5	363.1	54.2	367.5
Apr	78.3	530.1	77.5	512.9	47.3	372.7	64.6	469.9	64.1	473.8
May	79.8	557.3	79.2	491.8	56.9	448.9	72.1	504.6	72.1	514.0
Jun	81.5	555.0	80.5	492.9	66.4	481.6	77.9	500.1	78.8	528.1
Jul	82.0	522.0	80.9	508.2	72.1	459.9	80.2	488.0	81.2	499.6
Aug	82.6	507.7	81.3	498.6	70.4	406.5	79.6	430.0	80.2	461.9
Sep	82.6	471.6	81.1	454.2	63.4	327.9	75.2	378.2	74.5	390.4
Oct	81.6	426.1	80.6	411.0	53.7	245.9	66.1	323.5	64.2	328.6
Nov	80.4	389.7	78.7	371.0	43.3	145.8	[illegible]	253.4	53.8	249.9
Dec	78.6	355.6	76.8	355.2	31.5	113.5	49.3	195.5	46.0	195.9
Ann	79.9	466.6	78.6	444.7	50.0	301.7	64.7	364.8	63.5	374.4

STATE:	South Carolina		South Dakota		South Dakota		South Dakota		South Dakota	
STATION:	Greenville		Huron		Pierre		Rapid City		Sioux Falls	
LATITUDE:	3454N		4423N		4423N		4403N		4334N	
LONGITUDE:	8213W		9813W		10017W		10304W		9644W	
ELEVATION:	296		393		526		966		435	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	42.3	197.9	12.5	132.4	15.6	143.8	21.9	147.1	14.2	144.5
Feb	44.4	266.3	17.9	202.0	20.4	215.7	25.8	224.2	19.4	217.6
Mar	50.9	360.3	29.0	302.1	29.8	327.2	31.2	333.3	30.0	312.5
Apr	61.0	460.4	45.8	415.0	46.3	437.8	44.6	431.0	46.1	418.5
May	69.1	498.8	57.0	507.6	57.4	533.4	55.2	511.8	57.7	513.7
Jun	75.9	520.3	67.1	569.9	67.4	595.3	64.2	578.1	67.6	569.6
Jul	78.3	496.4	73.7	592.1	75.2	617.9	72.6	603.0	73.3	583.1
Aug	77.5	460.9	72.1	513.3	73.9	540.5	71.6	532.4	71.8	500.3
Sep	71.7	381.3	60.7	384.6	62.1	405.8	60.5	411.7	60.9	382.4
Oct	61.7	320.1	49.6	268.1	62.1	285.3	50.0	288.5	50.2	262.7
Nov	51.0	238.8	32.4	156.5	33.8	168.9	35.4	175.4	33.1	164.8
Dec	42.9	181.8	19.2	109.9	21.5	119.9	26.5	129.2	20.0	119.6
Ann	60.6	365.3	44.8	346.1	46.2	366.0	46.6	363.8	45.4	349.9

STATE:	Tennessee		Tennessee		Tennessee		Tennessee		Texas	
STATION:	Chattanooga		Knoxville		Memphis		Nashville		Abilene	
LATITUDE:	3502N		3549N		3503N		3607N		3226N	
LONGITUDE:	8512W		8359W		8959W		8641W		9941W	
ELEVATION:	210		299		87		180		534	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	40.2	171.0	40.6	168.4	40.5	185.2	38.3	157.2	43.7	250.6
Feb	42.9	232.9	42.8	234.2	43.8	256.3	41.0	223.4	47.9	320.8
Mar	49.8	319.0	49.9	323.0	51.0	346.7	48.7	306.5	54.5	427.5
Apr	60.5	420.4	60.3	433.7	62.5	444.5	60.1	418.7	65.2	500.0
May	68.5	469.8	68.4	489.1	70.9	511.3	68.5	495.0	72.4	552.6
Jun	76.0	496.7	75.5	515.8	78.6	554.6	76.6	532.5	80.3	599.1
Jul	78.8	470.7	78.2	489.4	81.6	534.9	79.6	513.0	83.9	580.2
Aug	78.0	442.1	77.3	451.9	80.4	494.7	78.5	471.1	83.6	530.6
Sep	71.9	362.2	71.6	375.2	73.6	399.0	72.0	379.2	76.1	433.3
Oct	60.8	300.6	60.9	304.0	63.0	326.7	60.9	302.1	66.1	356.8
Nov	48.9	209.7	49.2	205.8	50.9	221.5	48.4	192.9	54.1	273.4
Dec	41.2	157.4	41.5	154.4	42.7	170.5	40.4	141.2	46.4	234.2
Ann	59.8	337.7	59.7	345.4	61.6	370.5	59.4	344.4	64.5	421.6

STATE:	Texas		Texas		Texas		Texas		Texas	
STATION:	Amarillo		Austin		Brownsville		Corpus Christi		Dallas	
LATITUDE:	3514N		3018N		2554N		2746N		3251N	
LONGITUDE:	10142W		9742W		9726W		9730W		9651W	
ELEVATION:	1098		189		4		13		149	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	36.0	260.4	49.7	234.5	60.3	247.6	56.3	243.6	45.4	222.8
Feb	39.7	337.3	53.3	305.0	63.4	308.0	59.6	311.2	49.4	290.5
Mar	45.6	442.4	59.5	387.6	67.7	395.4	64.9	387.9	55.8	385.7
Apr	56.5	547.7	68.6	435.4	74.9	471.2	72.8	445.5	66.4	441.3
May	65.6	599.9	75.2	497.3	79.3	522.7	77.9	506.3	73.8	512.3
Jun	74.6	649.1	81.6	562.0	82.8	573.8	82.4	567.9	81.6	579.1
Jul	78.7	618.6	84.6	571.1	84.4	600.1	84.8	593.0	85.7	575.6
Aug	77.6	570.5	84.7	523.9	84.4	549.9	85.1	540.0	85.8	529.0
Sep	69.8	477.5	78.9	435.6	81.6	459.5	81.0	457.6	78.2	430.5
Oct	59.5	380.7	70.1	361.6	75.7	390.3	73.9	384.2	68.0	346.1
Nov	46.3	280.2	59.1	267.6	68.1	286.0	64.9	282.8	55.9	254.0
Dec	38.5	236.4	52.3	223.8	62.8	233.9	59.1	229.1	48.2	211.6
Ann	57.4	450.0	68.1	400.5	73.8	419.9	71.9	412.4	66.2	398.2

STATE:	Utah		Utah		Utah		Virginia		Virginia	
STATION:	Bryce Canyon		Cedar City		Salt Lake City		Norfolk		Richmond	
LATITUDE:	3742N		3742N		4046N		3654N		3730N	
LONGITUDE:	11209W		11306W		11158W		7612W		7720W	
ELEVATION:	2313		1712		1288		9		50	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	19.8	247.8	28.7	239.3	28.0	173.4	40.5	184.0	37.5	171.4
Feb	23.2	335.2	33.1	320.0	33.4	268.2	41.4	252.8	39.4	237.9
Mar	28.7	457.0	38.4	443.6	39.6	394.5	48.1	347.4	46.9	328.3
Apr	37.7	578.6	47.1	567.5	49.2	513.8	57.8	454.8	57.8	424.8
May	46.2	665.6	56.2	669.2	58.3	640.8	66.7	512.0	66.5	477.9
Jun	46.2	720.1	65.0	733.9	66.2	694.6	74.5	542.6	74.2	507.9
Jul	61.6	657.5	73.2	679.0	76.7	702.6	78.3	502.7	77.9	481.3
Aug	59.9	585.0	71.3	607.9	74.5	611.3	76.9	455.8	76.3	434.2
Sep	52.9	520.8	63.2	533.9	64.8	500.0	71.8	378.6	70.0	365.6
Oct	42.8	397.3	51.5	395.9	52.4	350.8	61.7	293.8	59.3	280.1
Nov	30.7	275.4	38.8	269.2	39.1	213.7	51.6	220.1	49.0	198.8
Dec	22.4	221.9	30.8	213.1	30.3	154.6	42.3	169.2	39.0	153.7
Ann	40.0	471.8	49.8	472.7	51.0	434.8	59.3	359.5	57.8	338.5

STATE:	Virginia		Vermont		Washington		Washington		Washington	
STATION:	Roanoke		Burlington		Olympia		Seattle-Tacoma		Spokane	
LATITUDE:	3719N		4428N		4658N		4727N		4733N	
LONGITUDE:	7958W		7309W		12254W		12218W		11732W	
ELEVATION:	358		104		61		122		721	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INS
Jan	36.4	179.2	16.8	104.5	37.2	72.9	38.2	71.0	25.4	85.4
Feb	38.1	244.0	18.6	164.6	41.0	136.4	42.3	134.3	32.2	164.3
Mar	45.3	335.3	29.1	255.0	43.2	229.2	44.1	230.4	37.5	282.3
Apr	55.9	429.0	43.0	351.6	48.2	340.5	48.7	350.9	46.1	405.5
May	64.4	478.4	54.8	427.0	54.0	442.6	54.9	464.9	54.7	520.2
Jun	71.7	510.4	65.2	469.0	58.9	459.3	59.8	488.7	61.5	565.0
Jul	75.2	487.2	69.8	466.8	63.6	518.8	64.5	609.8	69.7	639.4
Aug	74.1	439.5	67.4	400.1	62.8	420.1	63.8	438.4	68.0	526.8
Sep	68.0	368.4	59.3	304.4	58.6	313.8	59.6	311.3	59.6	389.3
Oct	57.8	293.0	48.8	200.9	50.6	172.6	52.2	178.0	47.8	228.1
Nov	46.7	207.4	37.0	101.6	43.3	92.0	44.6	91.5	35.5	107.9
Dec	37.4	160.3	22.6	76.8	39.5	60.1	40.5	57.3	29.0	69.2
Ann	55.9	344.3	44.4	276.9	50.1	271.5	51.1	285.5	47.3	332.0

STATE:	Washington		Washington		Wisconsin		Wisconsin		Wisconsin	
STATION:	Windby Island		Yakima		Eau Claire		Green Bay		La Crosse	
LATITUDE:	4821N		4634N		4452N		4424N		4352N	
LONGITUDE:	12240W		12032W		9129W		8808W		9115W	
ELEVATION:	17		325		273		214		205	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	0.0	76.7	27.5	99.0	11.7	122.5	15.4	122.4	16.1	130.5
Feb	0.0	144.3	35.7	180.7	15.4	202.5	18.0	196.6	20.0	207.4
Mar	0.0	248.9	41.8	304.4	27.3	295.7	28.6	299.5	31.1	298.6
Apr	0.0	364.8	49.5	433.4	44.5	386.8	43.8	390.2	47.6	386.9
May	0.0	477.5	57.9	544.8	56.2	455.9	54.5	466.3	59.0	464.6
Jun	0.0	493.7	64.5	588.3	66.1	507.7	64.5	517.5	68.5	516.8
Jul	0.0	537.4	70.7	639.6	70.5	511.7	69.2	512.2	72.8	515.5
Aug	0.0	432.0	67.6	535.6	68.4	439.6	67.7	439.9	71.4	452.0
Sep	0.0	318.3	61.3	402.3	58.7	324.5	58.9	330.4	61.8	336.9
Oct	0.0	177.7	50.1	241.6	48.7	224.1	49.2	222.6	51.8	234.2
Nov	0.0	96.7	38.4	120.5	32.0	122.2	34.1	126.1	35.4	134.0
Dec	0.0	63.2	31.3	80.0	18.0	92.4	20.9	94.9	21.8	100.2
Ann	0.0	285.9	49.8	347.5	43.1	307.1	43.7	309.9	46.4	314.8

STATE:	Wisconsin		Wisconsin		West Virginia		West Virginia		Wyoming	
STATION:	Madison		Milwaukee		Charleston		Huntington		Casper	
LATITUDE:	4308N		4257N		3822N		3822N		4255N	
LONGITUDE:	8920W		8754W		8136W		8233W		10628W	
ELEVATION:	262		211		290		255		1612	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	16.8	139.7	19.4	130.0	34.5	135.2	34.3	142.7	23 2	185.3
Feb	20.3	218.1	22.5	199.8	36.5	191.6	36.1	205.3	26.8	274.9
Mar	30.2	308.1	31.4	295.3	44.5	273.8	44.3	289.4	31.0	390.9
Apr	45.3	379.3	44.7	391.3	55.9	367.7	55.7	392.7	42.7	500.9
May	56.0	472.8	54 2	479.7	64.5	444.7	64.5	463.9	52.7	597.7
Jun	65.8	528.4	64.5	536.3	72.0	481.7	72.4	500.1	61.9	678.5
Jul	70.1	524.7	69.9	532.1	75.0	456.4	75.3	479.8	71.0	687.5
Aug	68.7	463.3	69.2	466.3	73.6	410.8	73.9	428.6	69.6	603.6
Sep	59.7	352.5	61.1	355.4	67.5	345.0	67.7	354.2	58.7	474.5
Oct	49.9	247.1	51.0	246.3	57.0	263.7	57.1	272.3	47.7	330.6
Nov	34.7	136.8	36.5	142.3	45.4	166.3	45.5	172.9	33.9	207.6
Dec	21.9	105.5	24.2	102.7	36.2	119.4	36.0	126.7	26.2	161.2
Ann	44.9	323.0	45.7	323.1	55.2	304.7	55.2	319.0	45.4	424.4

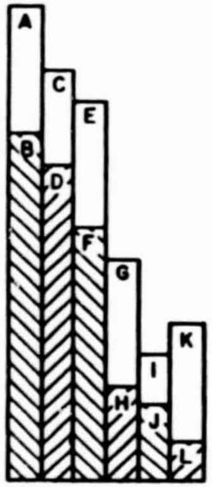
STATE:	Wyoming		Wyoming		Wyoming	
STATION:	Cheyenne		Rock Springs		Sheridan	
LATITUDE:	4109N		4136N		4446N	
LONGITUDE:	10449W		10904W		10658W	
ELEVATION:	1872		2056		1209	
MONTH	TEMP	INSLN	TEMP	INSLN	TEMP	INSLN
Jan	26.6	207.7	19.2	199.4	21.0	140.4
Feb	29.0	289.6	23.4	295.5	25.9	213.8
Mar	31.6	388.7	28.9	415.0	31.0	326.8
Apr	42.7	480.2	40.1	527.3	43.6	417.0
May	52.4	541.0	50.4	635.9	53.1	510.7
Jun	61.3	612.5	58.9	698.3	61.1	584.8
Jul	69.1	604.9	68.2	690.9	70.4	631.7
Aug	67.6	533.2	66.1	607.6	69.2	544.1
Sep	58.2	452.3	56.4	497.1	57.9	407.4
Oct	47.9	336.8	44.7	354.2	47.8	272.7
Nov	35.5	223.2	30.7	224.1	33.4	160.3
Dec	29.2	182.0	22.6	176.5	25.5	119.7
Ann	45.9	404.3	42.5	443.5	45.0	360.8

APPENDIX C

AVAILABILITY OF POND-SUITABLE LAND IN THE RESIDENTIAL, COMMERCIAL AND INSTITUTIONAL BUILDINGS SECTOR

CASE STUDY RESULTS BY THE BENHAM GROUP, OKLAHOMA CITY, OKLAHOMA

Legend



A - Total city acreage

B - Total city pond-suitable land

C - Total city developed acreage

D - Total city developed pond-suitable land

E - Total city undeveloped acreage

F - Total city undeveloped pond-suitable land

G - Total undeveloped residential acreage

H - Total undeveloped residential pond-suitable land

I - Total undeveloped commercial acreage

J - Total undeveloped commercial pond-suitable land

K - Total undeveloped institutional acreage

L - Total undeveloped institutional pond-suitable land

- Estimated pond-suitable acreage is below the scale of the graph (100)

- Estimated undeveloped and pond-suitable acreage is below the scale of the graph (<100)

Note: Acreage estimates are on a logarithmic scale.

Figure C-1. Availability of Pond-Suitable Land: Legend

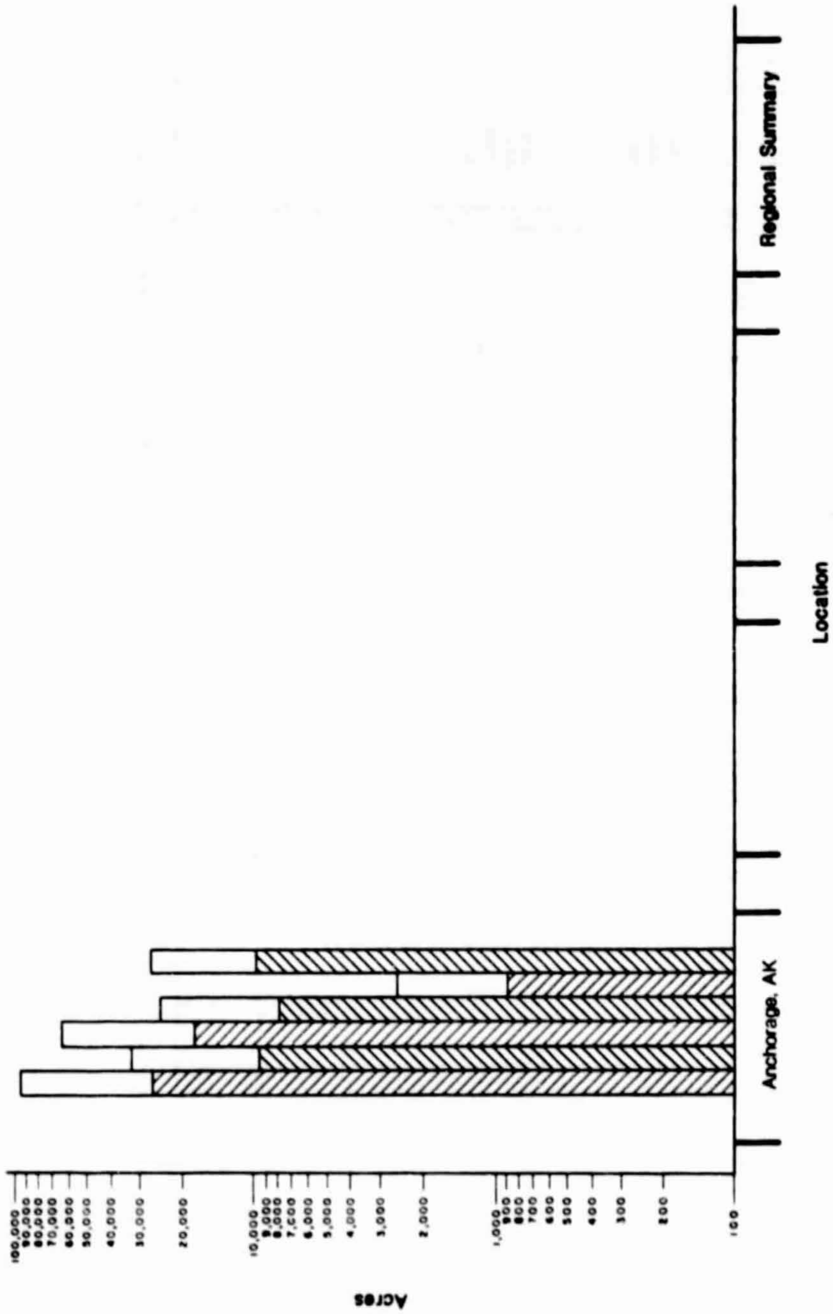


Figure C-2. Availability of Pond-Suitable Land: Alaska Region

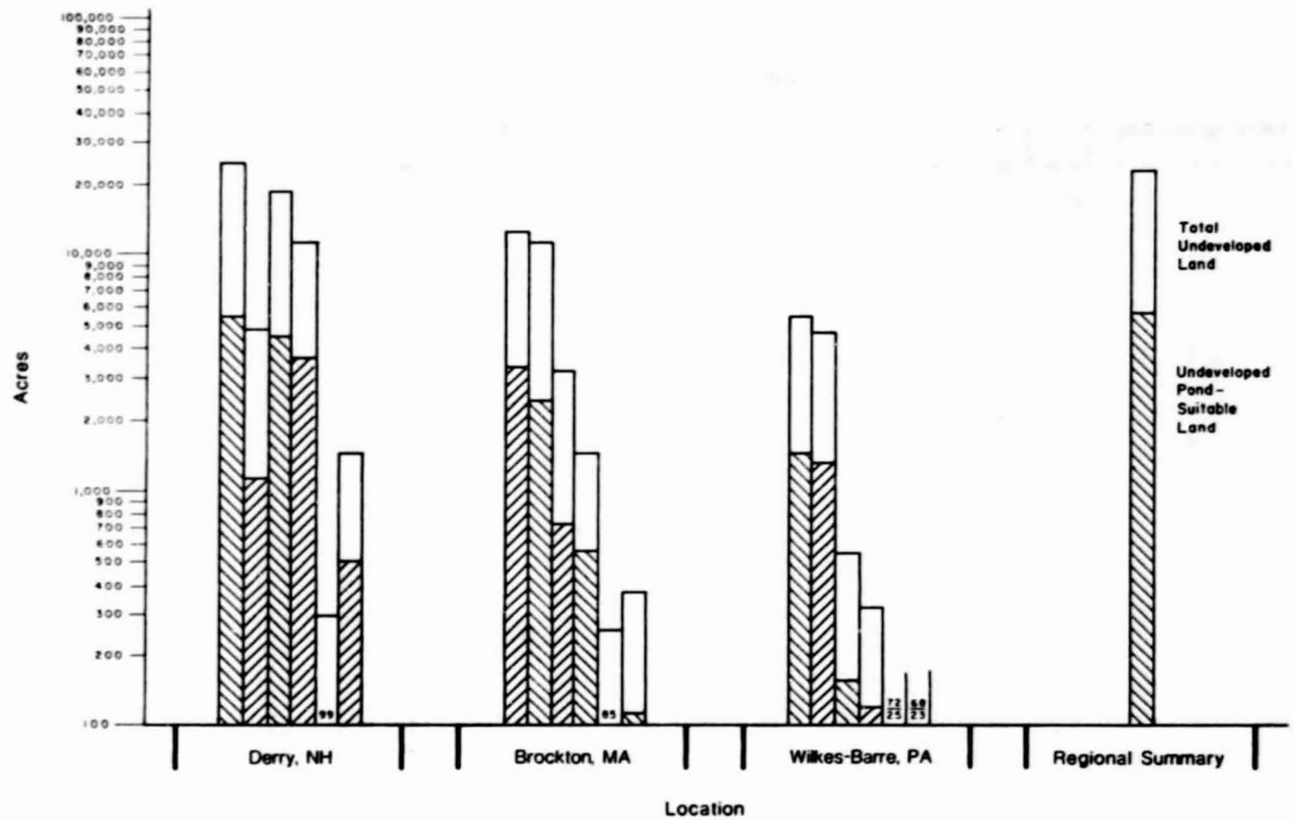


Figure C-3. Availability of Pond-Suitable Land: Atlantic Northeast Region

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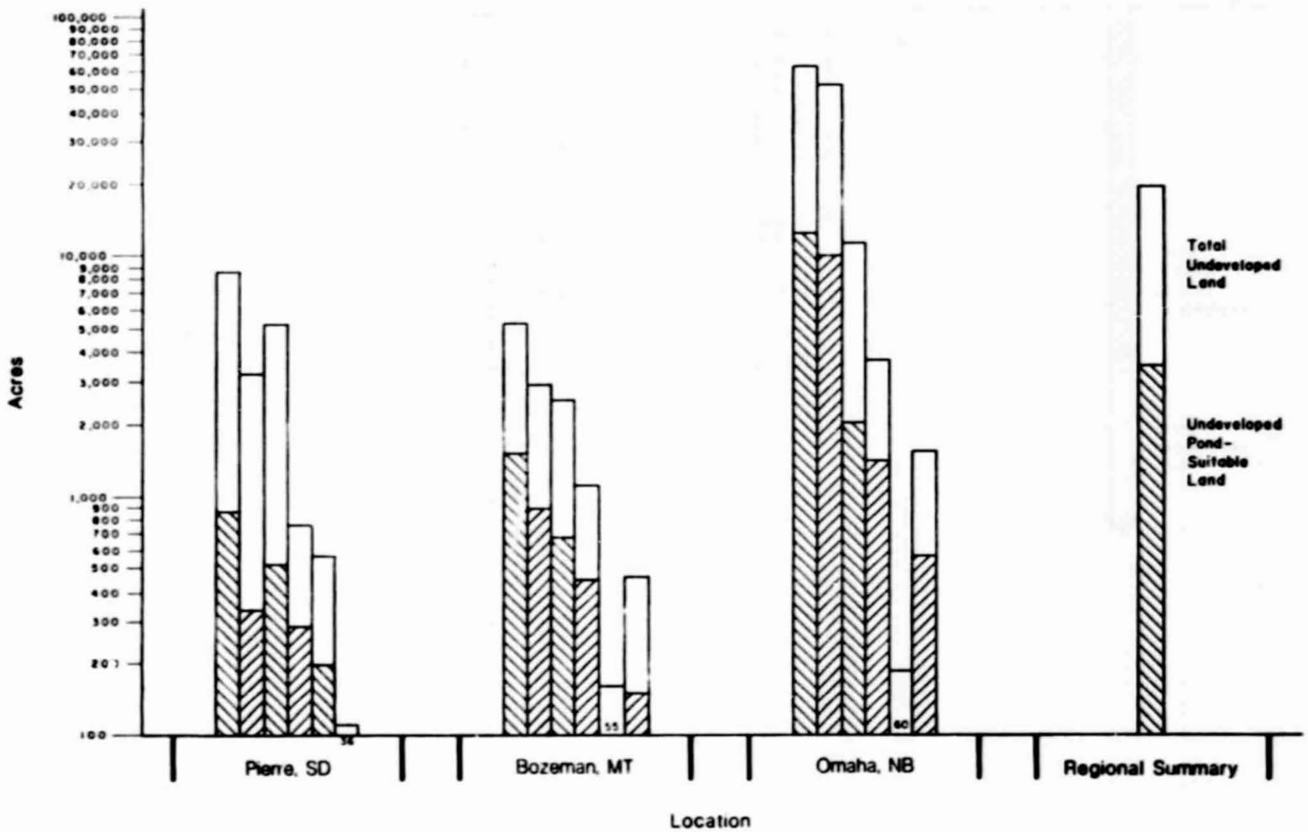

Figure C-4. Availability of Pond-Suitable Land: Black Hills Region

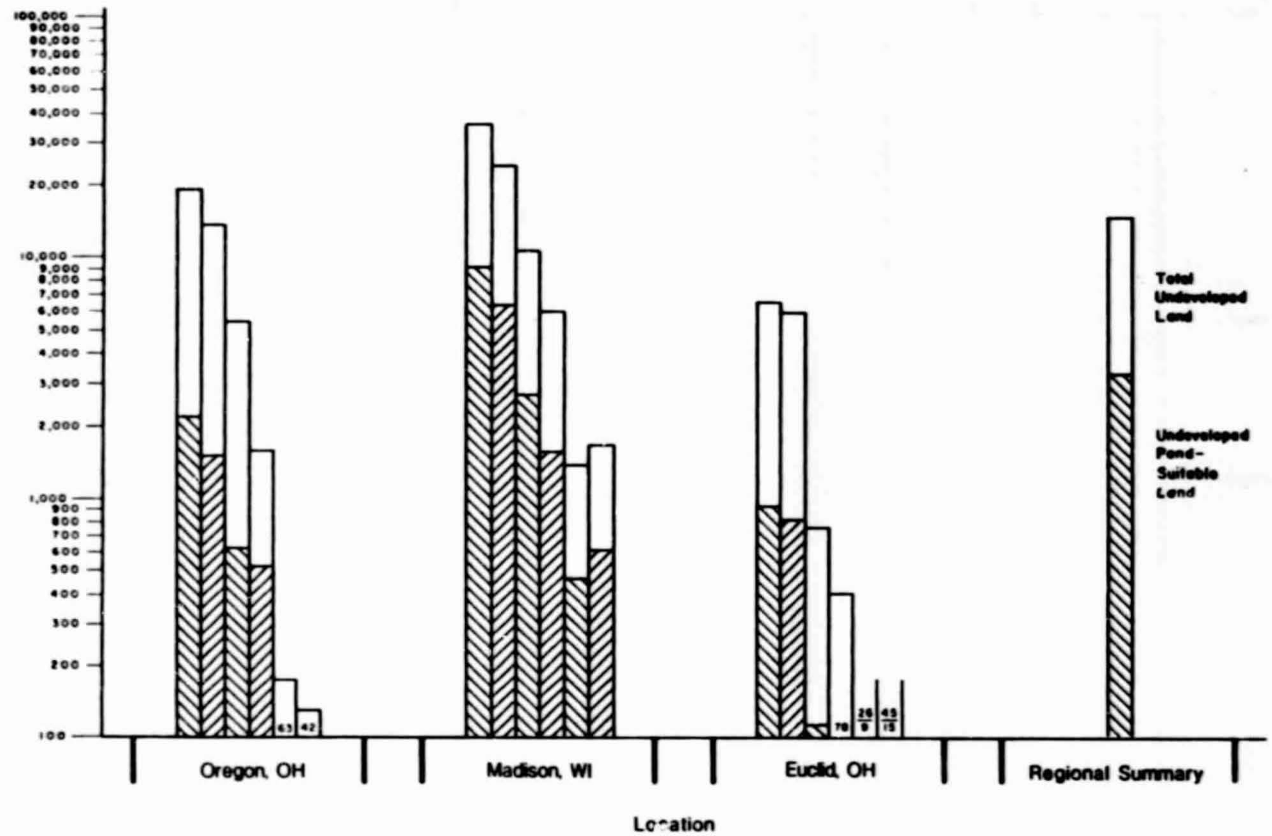

Figure C-5. Availability of Pond-Suitable Land: Great Lakes Region

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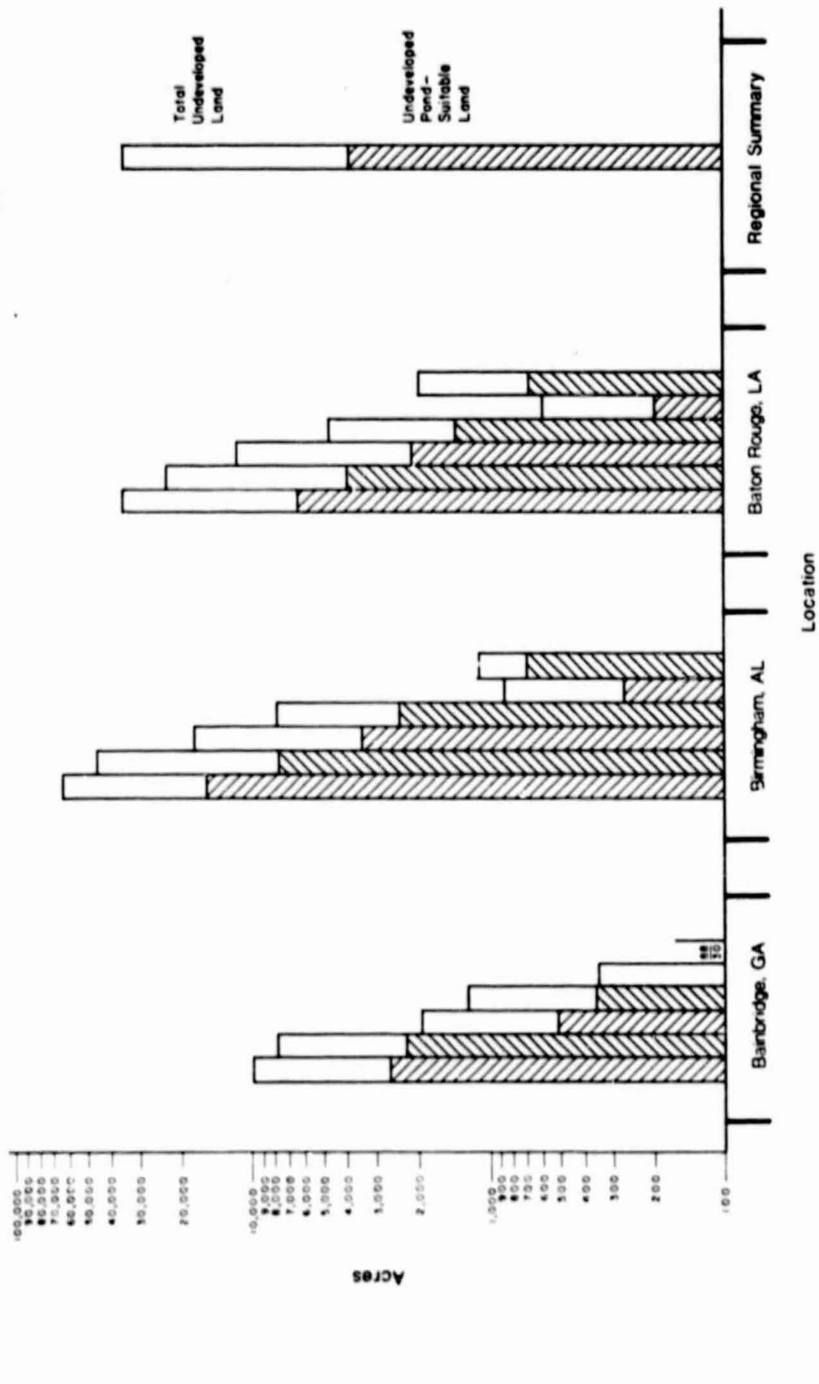

Figure C-6. Availability of Pond-Suitable Land: Gulf Coast Region

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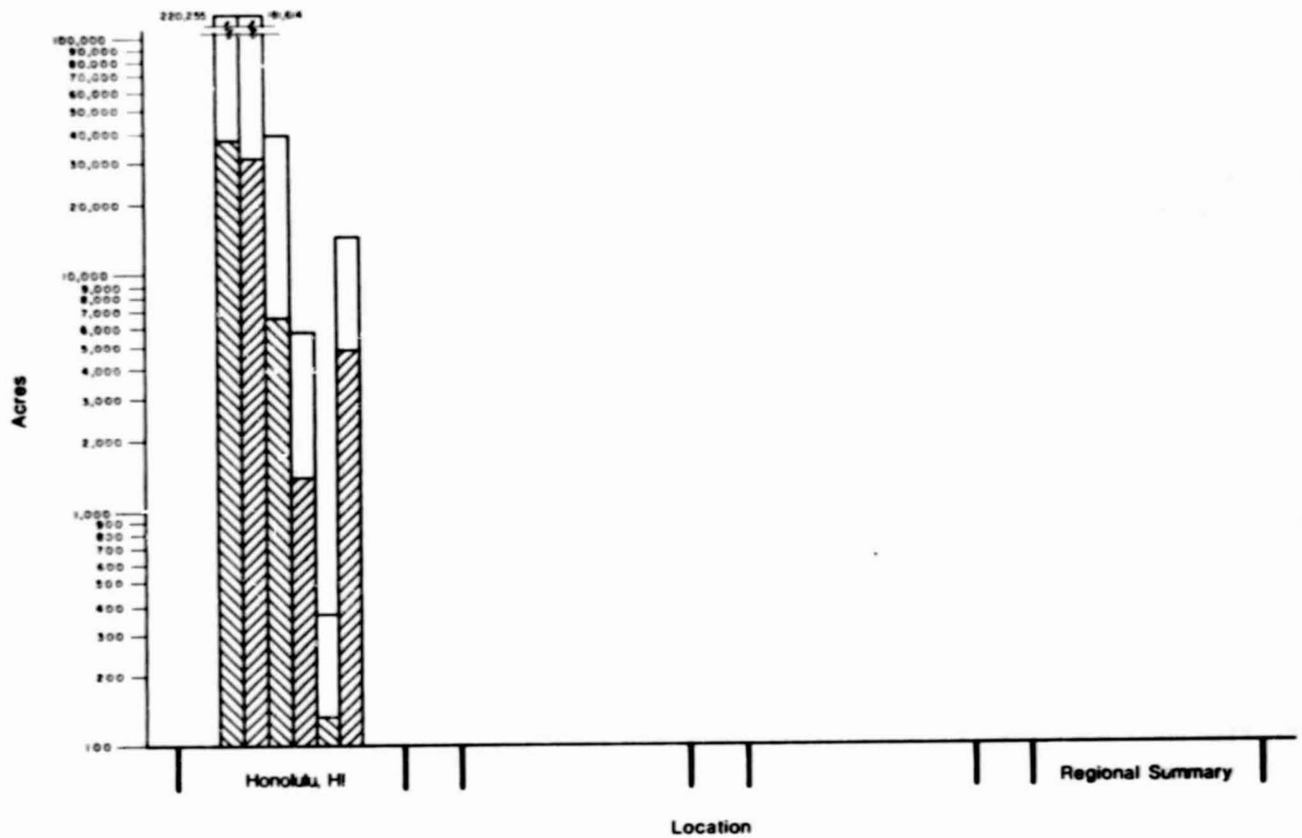

Figure C-7. Availability of Pond-Suitable Land: Hawaii Region

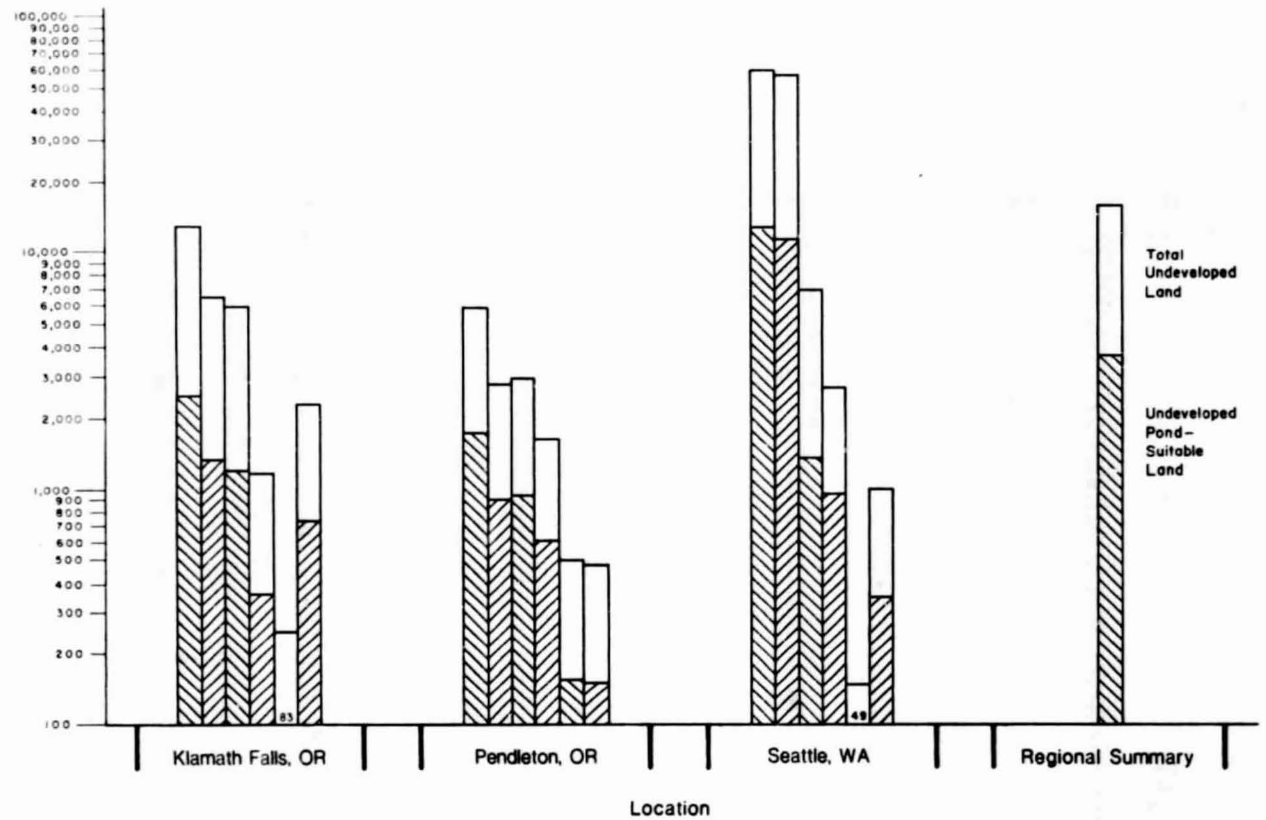

Figure C-8. Availability of Pond-Suitable Land: Pacific Northwest Region

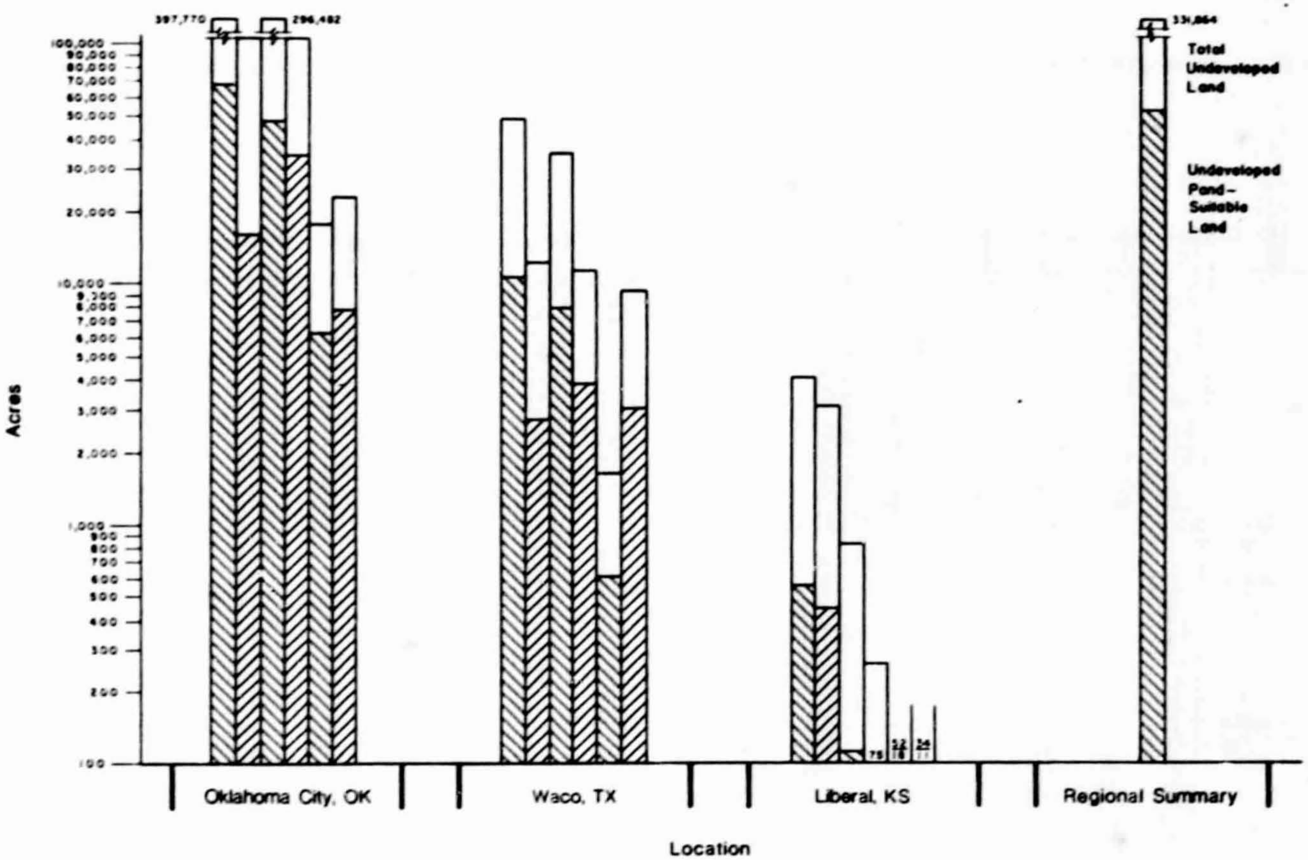

Figure C-9. Availability of Pond-Suitable Land: Red River Region

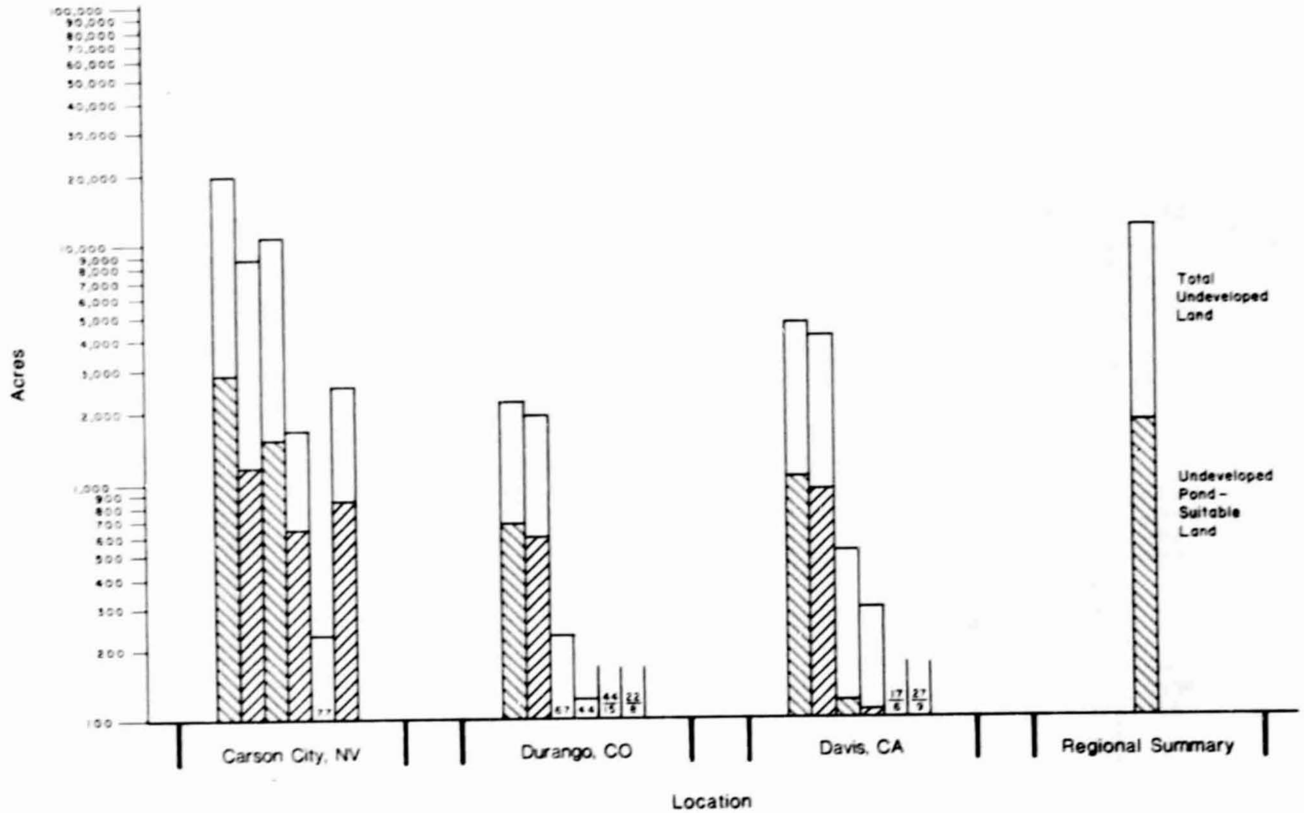

Figure C-10. Availability of Pond-Suitable Land: Salt Lake Region

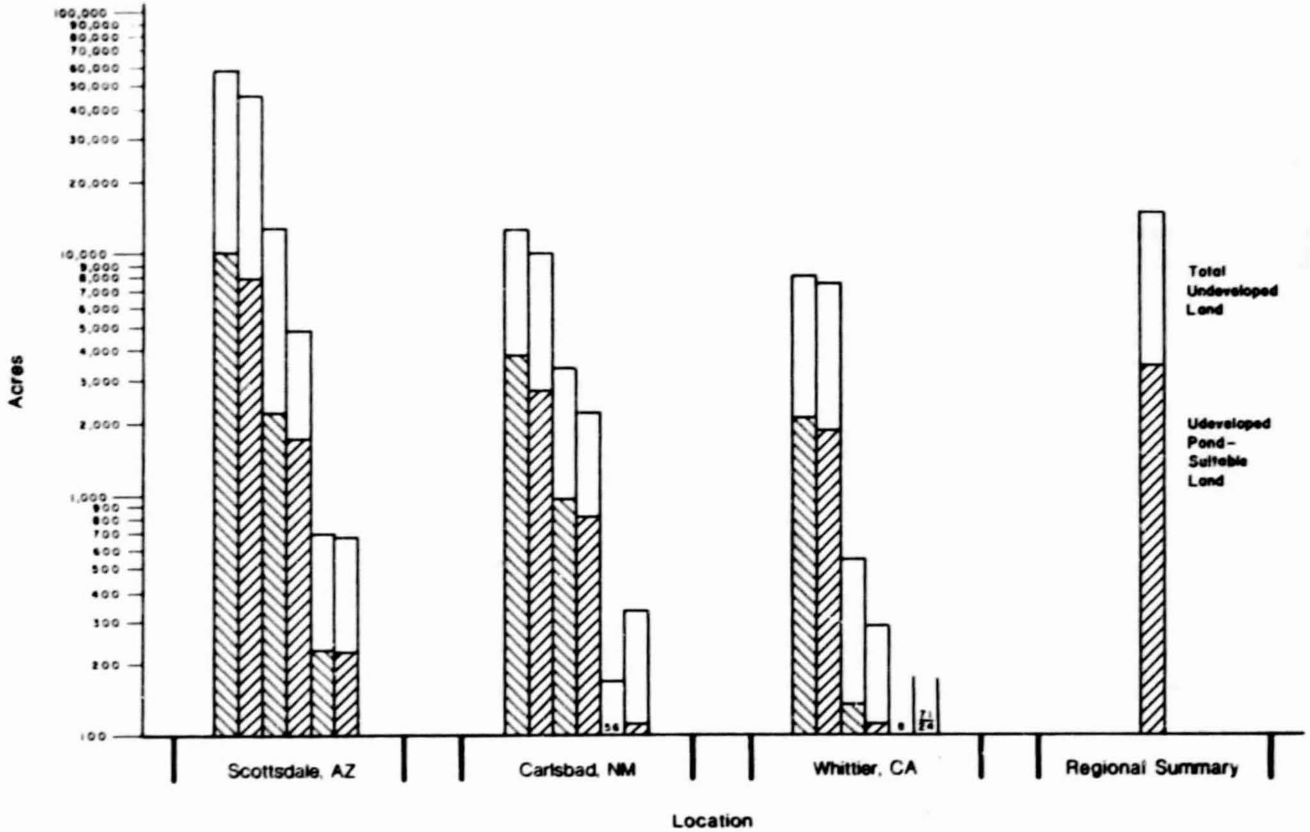

Figure C-11. Availability of Pond-Suitable Land: Southwest Region

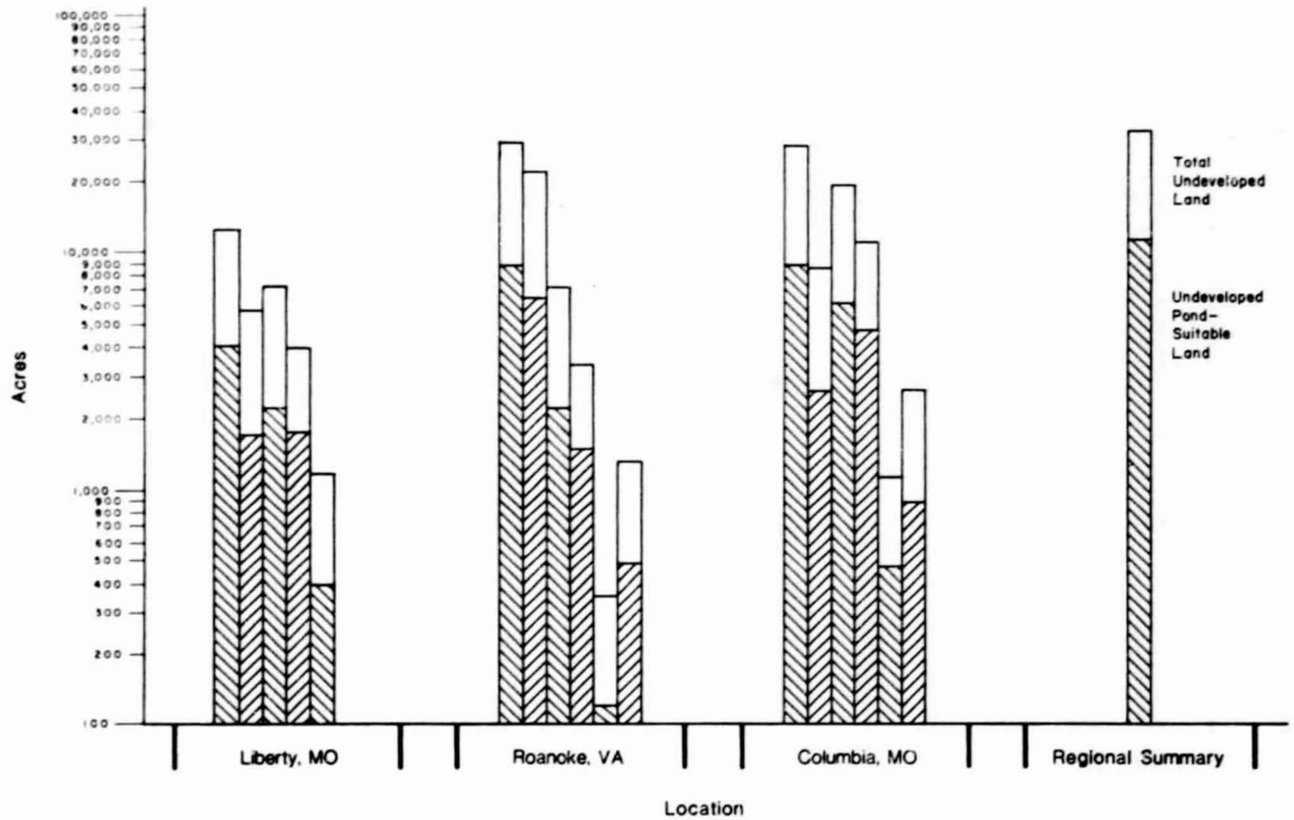

Figure C-12. Availability of Pond-Suitable Land: Tennessee Valley Region

APPENDIX D

LAND VALUES IN THE RESIDENTIAL, COMMERCIAL AND INSTITUTIONAL BUILDINGS SECTOR

CASE STUDY RESULTS BY THE BENHAM GROUP, OKLAHOMA CITY, OKLAHOMA

Legend

R Residential

C Commercial

I Institutional

▲ Low-range values

● Medium-range values

■ High-range values

Reveals price ranges within development categories.

Compares a given price range among the development categories.

Note: Dollar values on a logarithmic scale.

Figure D-1. Land-Value Comparisons: Legend

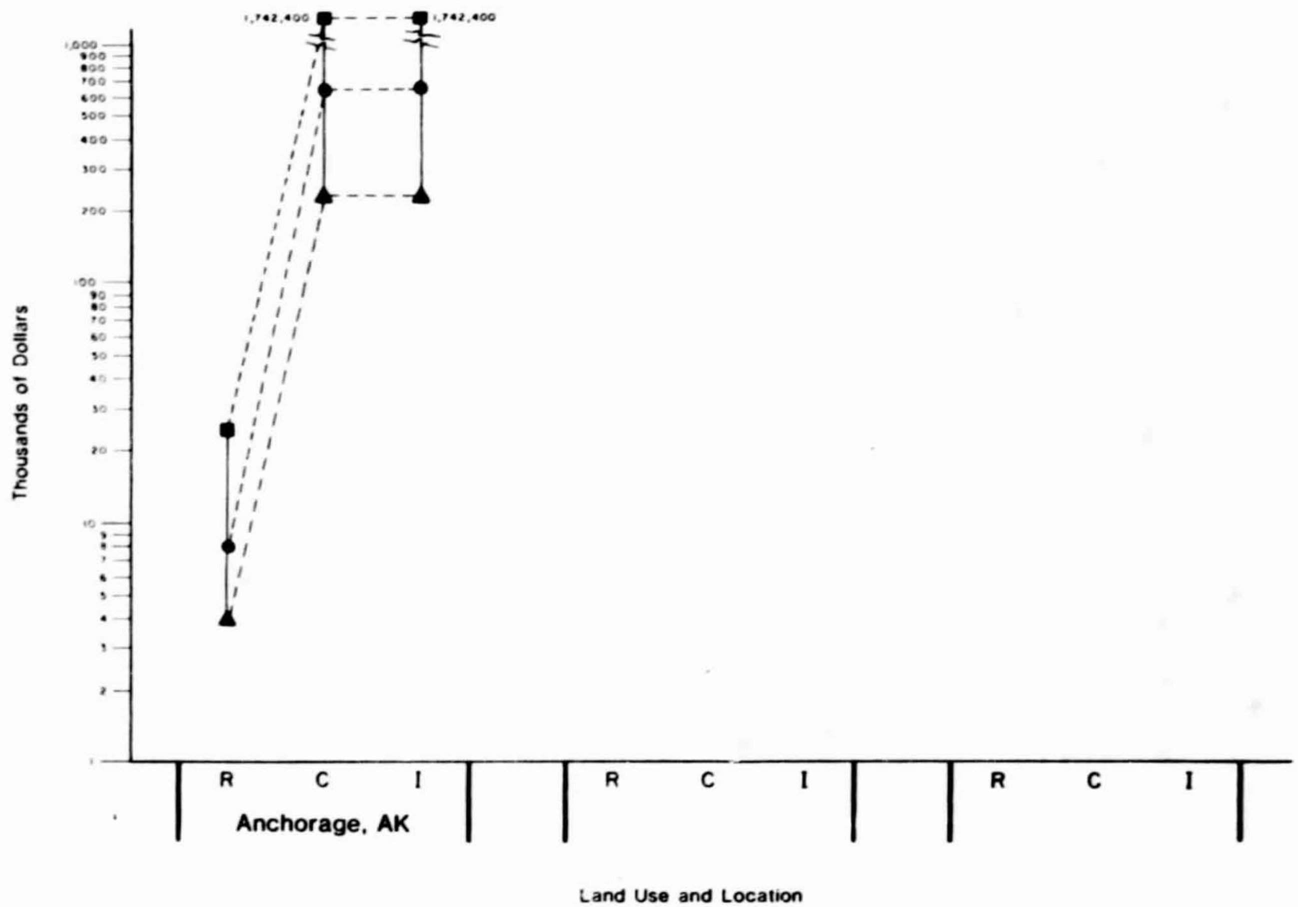

Figure D-2. Land-Value Comparison: Alaska Region (10^3\$/acre)

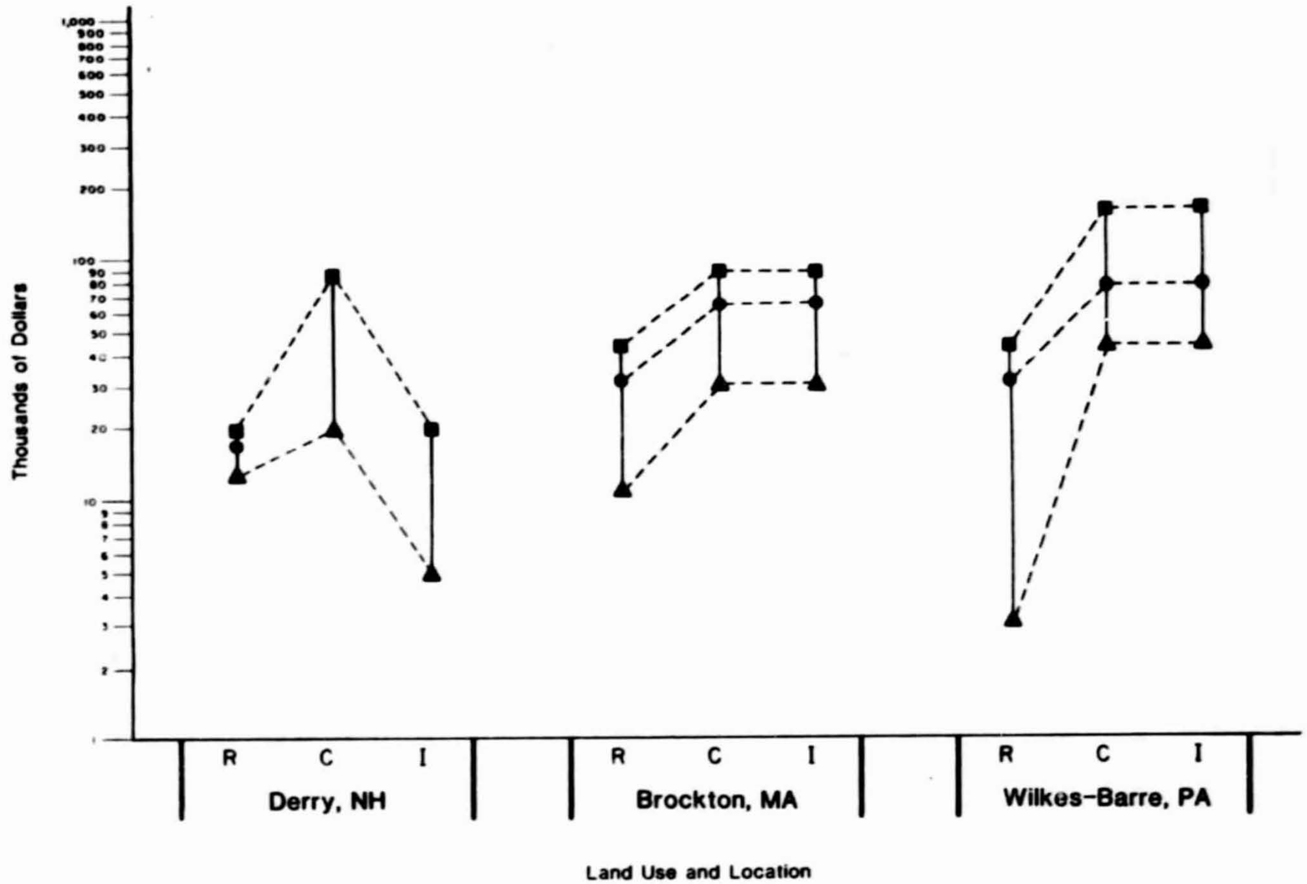

Figure D-3. Land-Value Comparisons: Atlantic Northeast Region (10^3\$/acre)

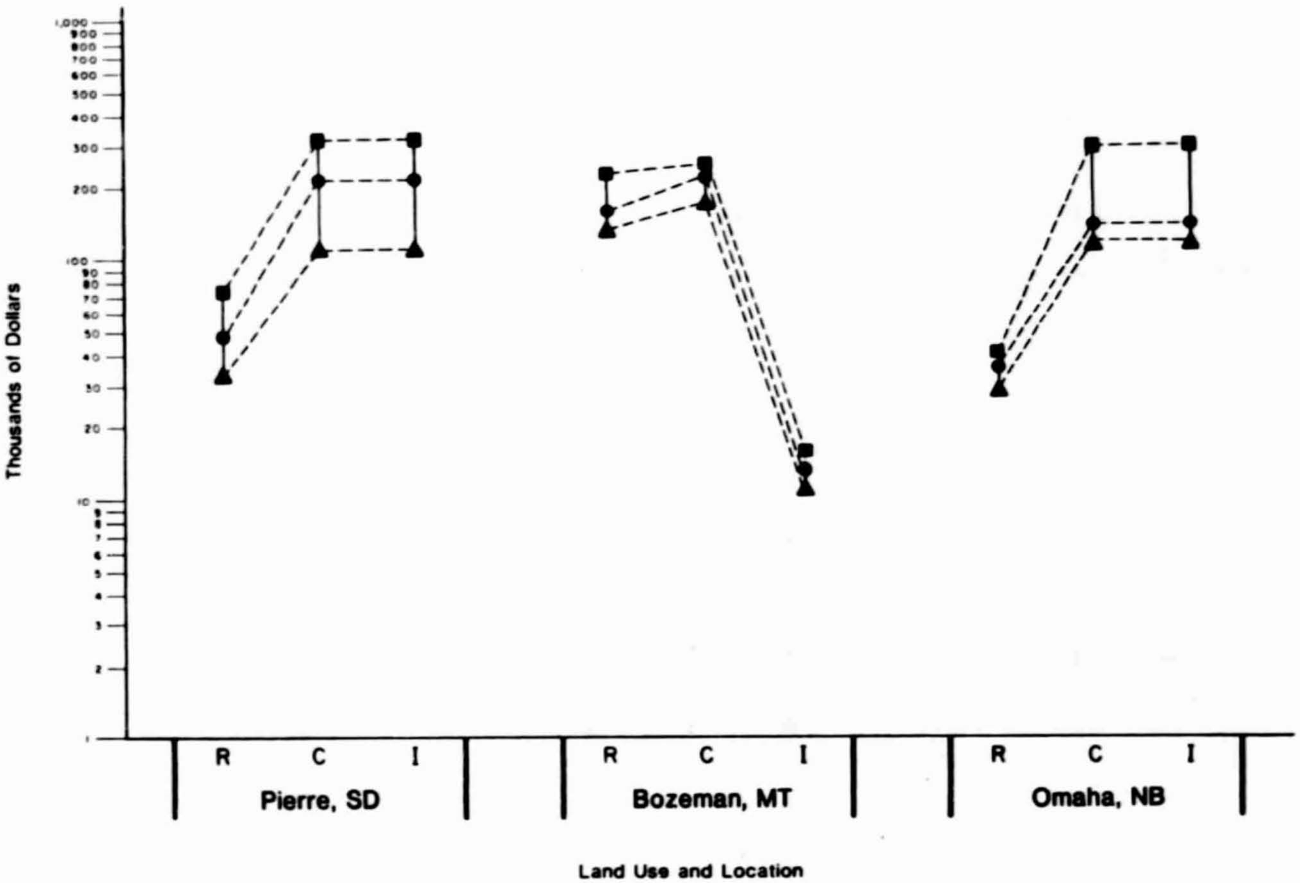

Figure D-4. Land Value Comparison: Blackhills Region (10^3\$/acre)

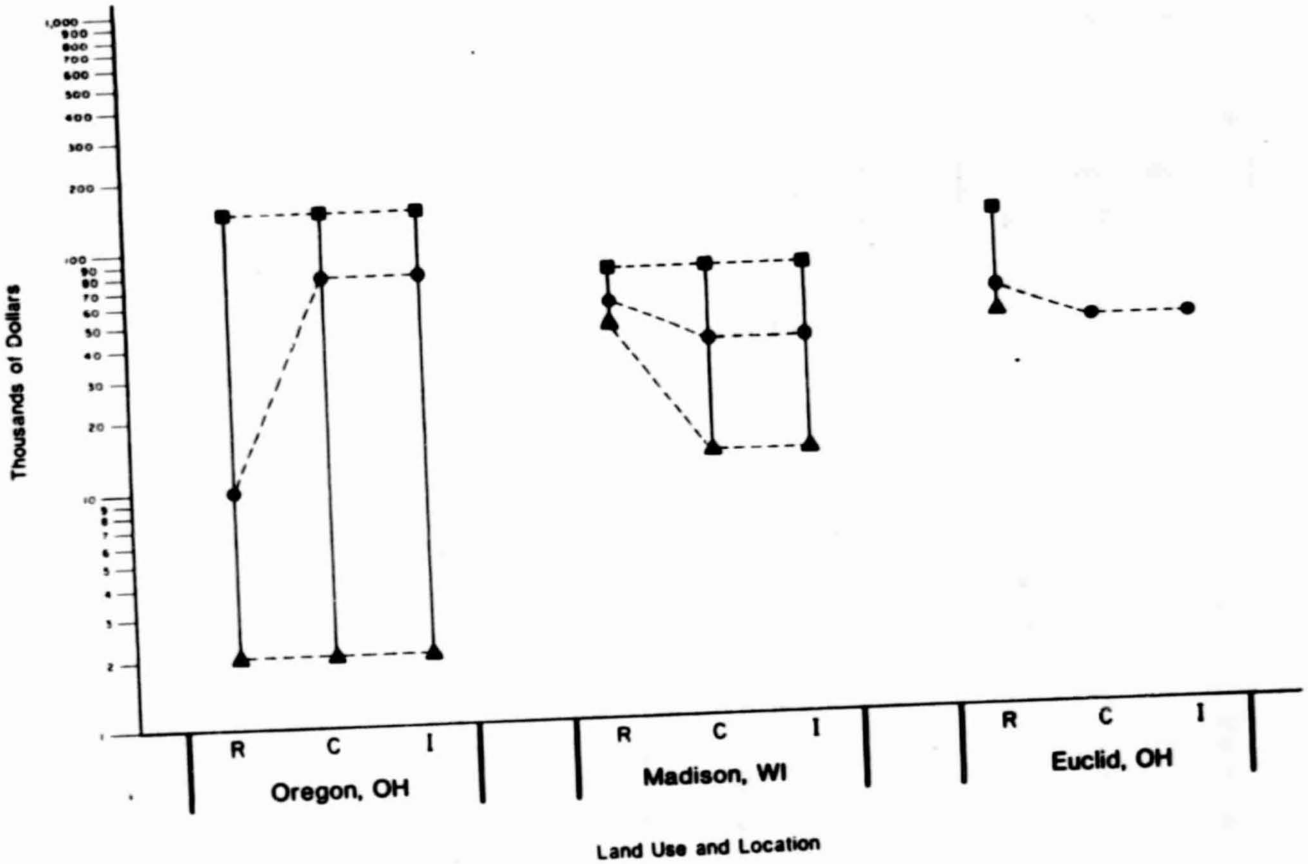

Figure D-5. Land-Value Comparison: Great Lakes Region (10^3\$/acre)

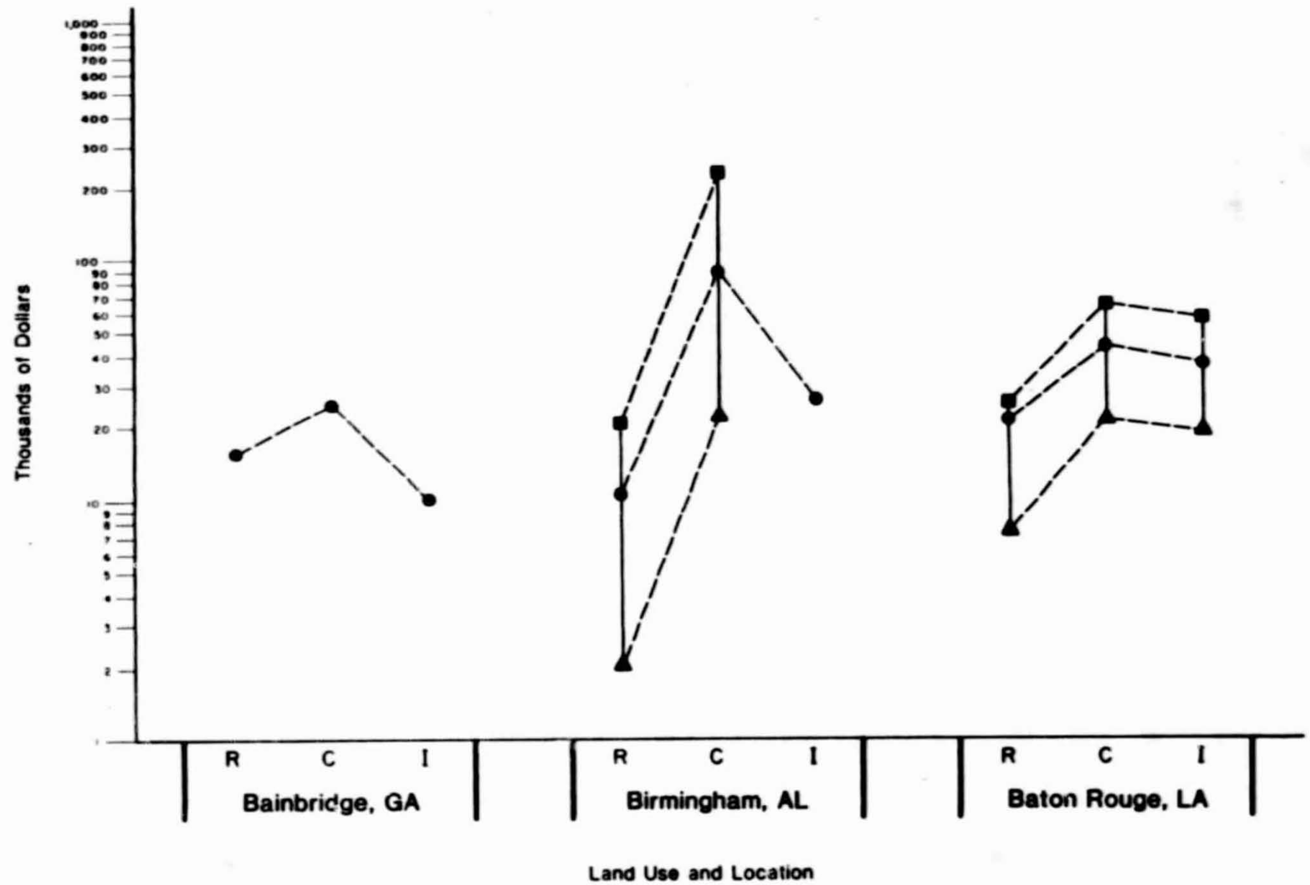

Figure D-6. Land-Value Comparisons: Gulf Coast Region

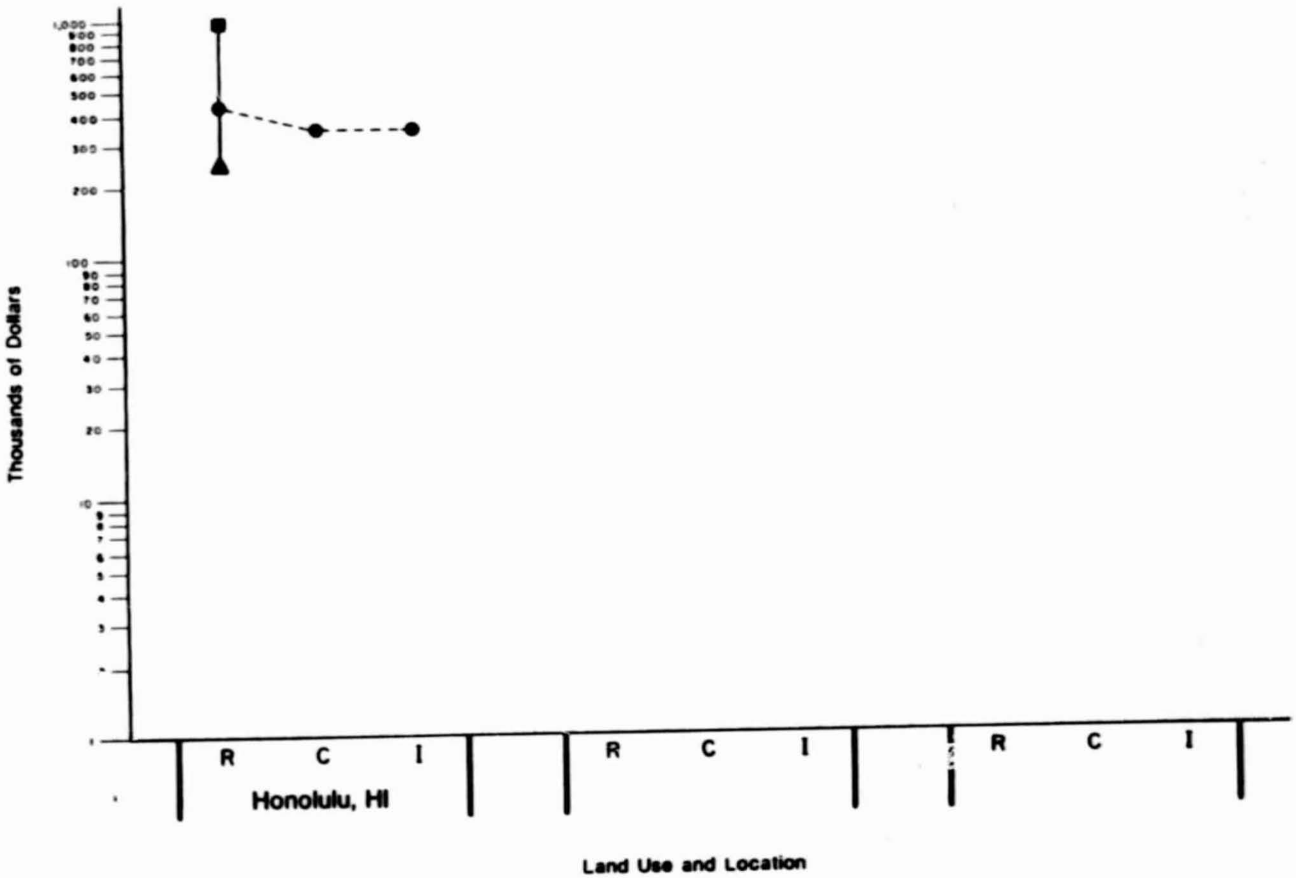

Figure D-7. Land-Value Comparisons: Hawaii Regions (10^3\$/acre)

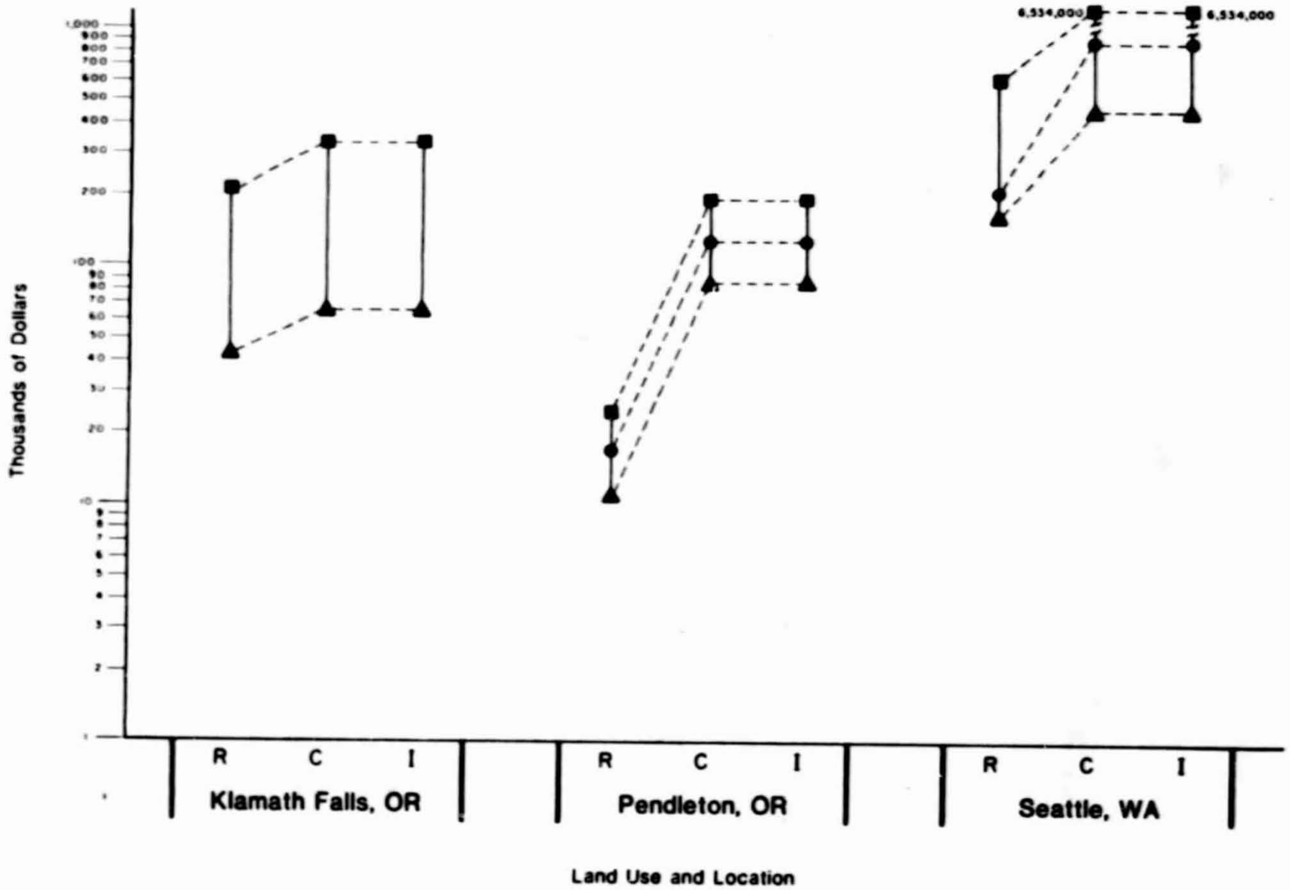

Figure D-8. Land-Value Comparisons: Pacific Northwest Region (10^3\$/acre)

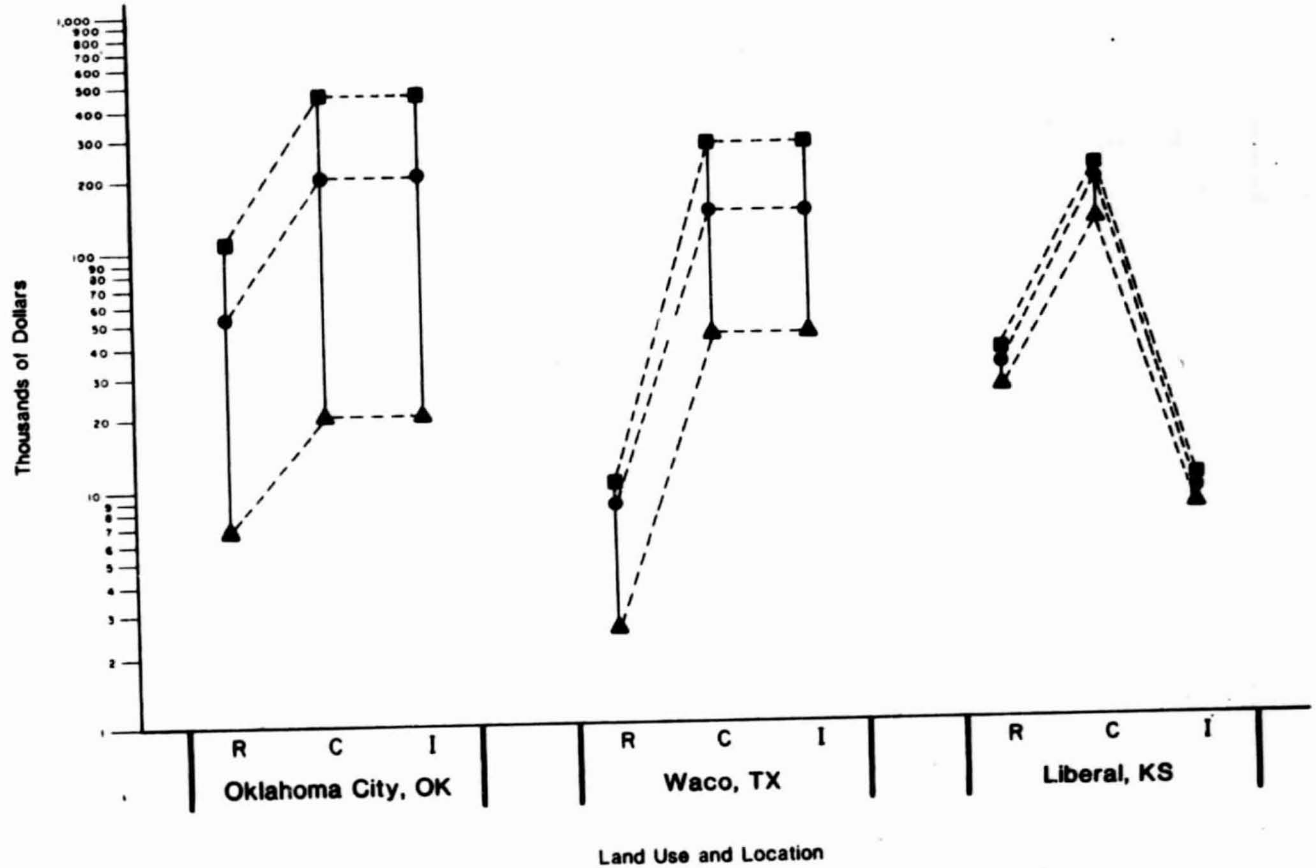

Figure D-9. Land-Value Comparisons: Red River Region (10^3\$/acre)

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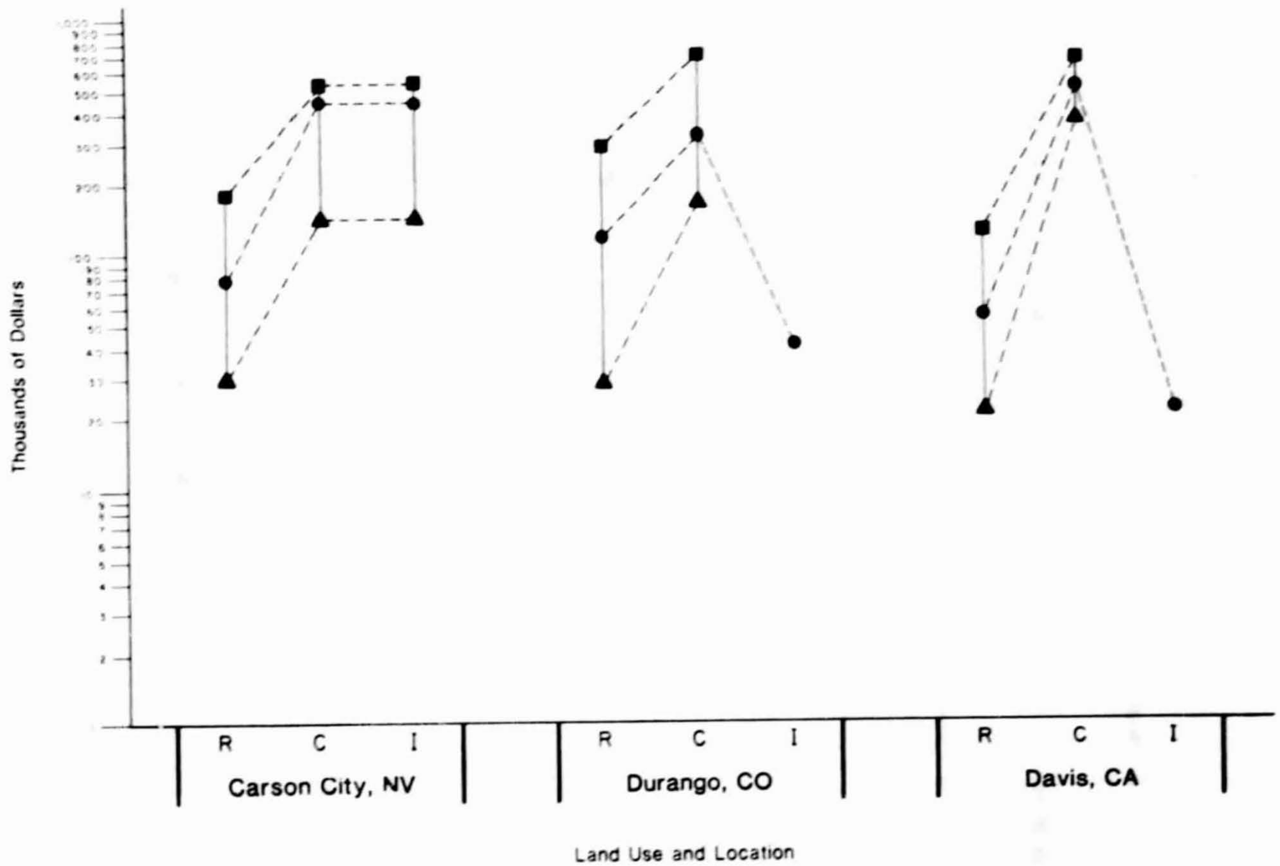

Figure D-10. Land-Value Comparisons: Salt Lake Regions (10^3\$/acre)

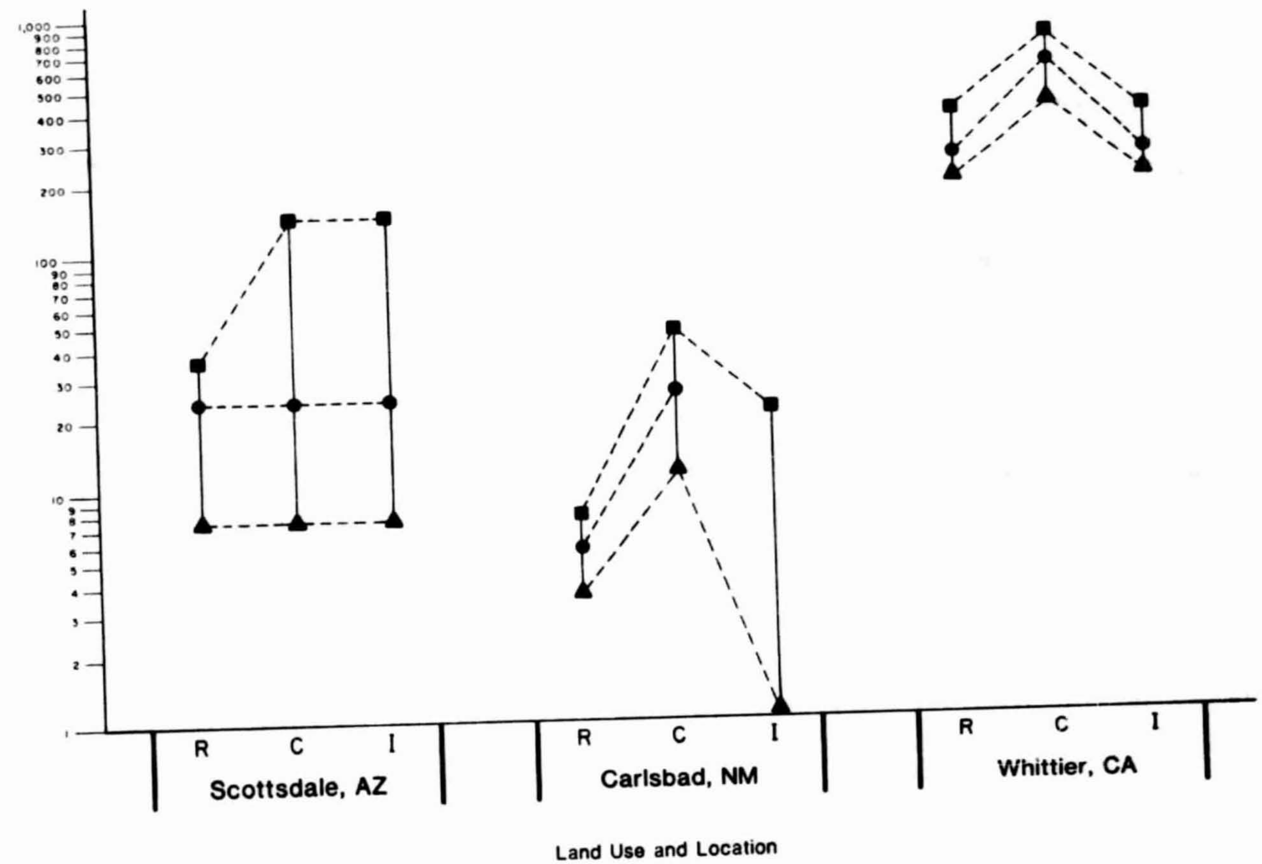

Figure D-11. Land-Value Comparisons: Southwest Region (10^3\$/acre)

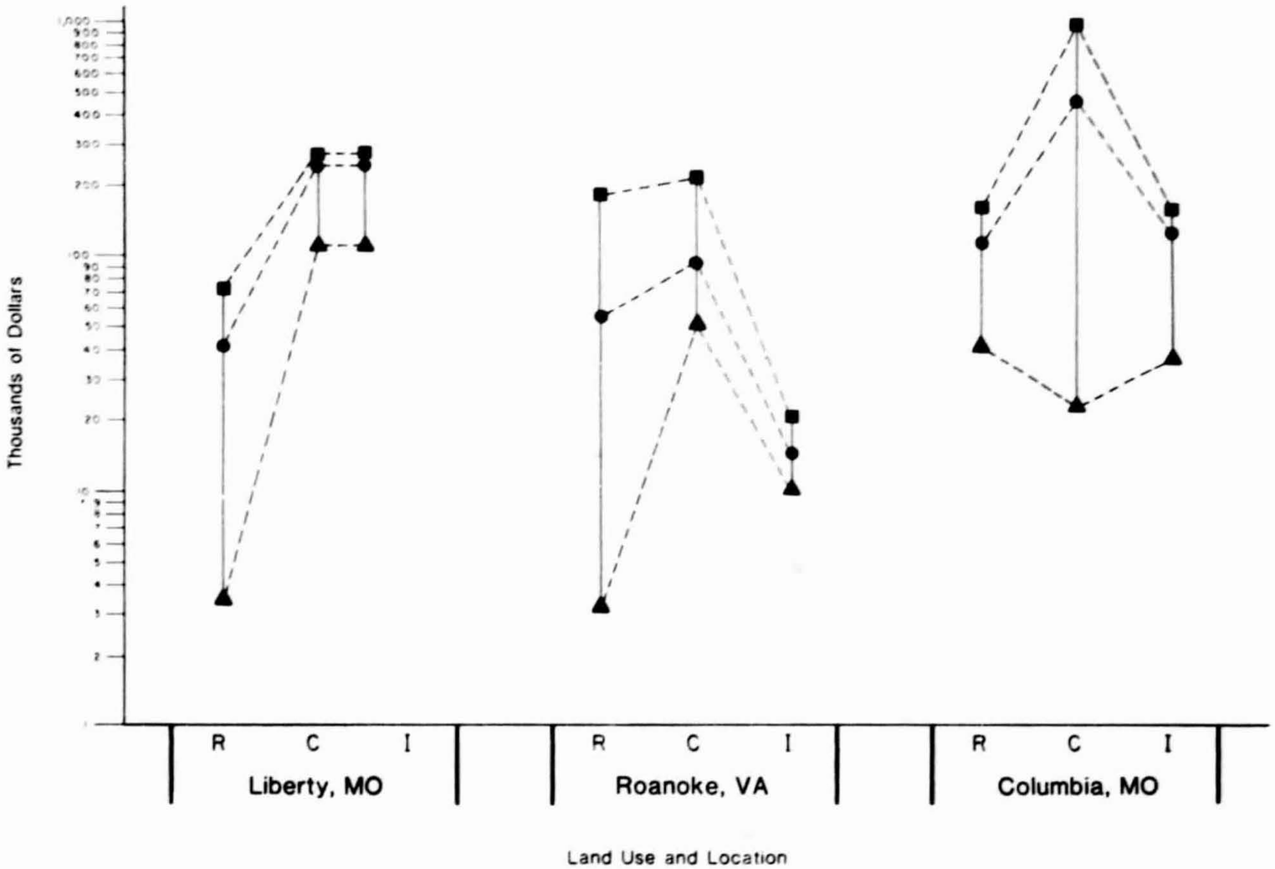

Figure D-12. Land-Value Comparisons: Tennessee Valley Region (10^3\$/acre)

APPENDIX E

RESIDENTIAL LAND COSTS

Table E-1. Average Size of Finished Residential Lots by States, 1976-1980 (ft^2)

State	1976	1977	1978	1979	1980
Maine	32,913	45,200	44,048	42,236	42,168
Rhode Island	—	—	—	33,604	35,684
Massachusetts	—	—	25,752	29,223	30,473
Connecticut	28,654	33,285	33,487	32,360	30,268
Delaware	11,042	12,125	14,736	22,596	25,052
N. Hampshire	37,061	40,572	24,556	25,843	21,832
Vermont	—	—	20,159	29,835	21,723
Pennsylvania	18,499	19,039	19,489	19,697	20,192
N. Carolina	23,388	17,752	18,713	19,421	19,498
Georgia	19,163	18,624	19,530	18,823	18,277
N. York	13,733	13,239	22,709	17,587	17,698
Alabama	14,892	16,743	18,391	17,344	16,973
W. Virginia	14,486	14,841	16,279	14,664	16,552
N. Jersey	19,934	16,880	16,049	16,480	16,083
Wisconsin	16,485	17,166	16,121	16,[illegible]21	15,867
Tennessee	13,523	13,410	16,396	15,720	15,487
Minnesota	14,288	15,200	14,911	14,593	14,810
Indiana	15,386	15,472	15,341	14,964	14,366
S. Carolina	—	11,103	12,919	13,407	14,356
Michigan	14,098	15,467	14,621	13,609	14,189
Maryland	13,715	14,365	16,309	15,387	13,779
Virginia	13,719	14,511	12,987	13,186	13,726
S. Dakota	9,467	10,909	14,373	17,575	13,476
Ohio	15,573	15,377	15,200	14,009	13,438
Mississippi	—	10,100	14,772	13,022	12,630
Missouri	10,636	11,283	11,422	11,709	12,012
Washington	11,316	11,733	10,721	11,948	11,870
Iowa	9,536	10,662	10,990	10,909	11,659
Kentucky	11,251	11,387	12,661	12,523	11,629
Montana	—	—	14,492	11,453	11,512
Louisiana	13,046	13,139	11,086	10,863	11,454
Florida	10,706	10,899	10,861	10,697	10,785
Kansas	11,080	11,224	11,405	10,956	10,767
Oklahoma	12,335	12,496	12,315	11,622	10,745
N. Dakota	—	—	—	14,783	10,707
Illinois	9,754	10,768	10,071	10,485	10,545
Texas	9,971	9,354	9,420	10,122	10,039
Idaho	12,712	11,330	10,922	10,185	9,883
Arkansas	—	11,335	16,512	—	9,871
N. Mexico	11,010	8,637	9,613	9,470	9,776
Utah	8,009	8,775	9,344	9,674	9,592
Oregon	9,779	8,798	8,974	9,108	9,265
Nebraska	9,198	9,266	9,122	9,074	8,958
Colorado	8,739	8,694	8,740	8,745	8,590
California	10,192	9,644	9,592	9,633	8,378
Alaska	—	—	—	9,605	8,071
Nevada	13,358	9,391	10,145	15,267	7,352
Hawaii	—	—	—	—	5,901
Washington, D.C.	—	—	—	2,323	3,974
Wyoming	—	—	—	—	—
Arizona	—	—	—	—	—
U.S. Total	11,589	12,241	12,364	12,828	12,807

Source:
Homer Hoyt Institute 1981.

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Table E-2 Average Cost of Finished Residential Lots by States, 1976-1980.

Average Cost of Finished Residential Lots by States 1976-1980

State	1976	1977	1978	1979	1980
Hawaii	$ —	$ —	$ —	$ —	$62.516
California	16.018	17.171	19.901	28.466	30.853
Washington, D.C.	—	—	—	21.409	23.732
Alaska	—	—	—	22.295	23.512
Maryland	14.690	13.640	15.624	17.788	20.408
Virginia	11.915	11.567	12.652	15.754	19.535
Connecticut	12.694	14.839	16.175	20.547	19.497
Illinois	10.641	11.917	14.302	16.484	19.219
N. Jersey	15.809	14.236	13.983	16.083	17.898
Oregon	7.507	8.985	11.458	14.205	16.243
Ohio	12.533	12.859	14.471	16.015	15.858
Pennsylvania	8.441	11.278	11.910	14.462	15.754
Louisiana	7.968	8.537	10.580	13.107	15.328
Vermont	—	—	11.183	13.010	15.163
Massachusetts	—	—	12.721	14.028	15.045
Rhode Island	—	—	—	13.320	14.908
Washington	6.971	8.222	9.494	12.014	14.848
Minnesota	6.917	7.716	10.631	12.757	14.662
Wisconsin	9.327	10.607	12.581	14.286	14.620
Colorado	8.288	9.493	10.952	12.613	14.580
New York	10.048	11.357	12.853	12.360	13.989
Utah	6.990	8.288	11.025	13.412	13.899
Michigan	10.102	10.063	10.713	12.986	13.687
Nevada	7.305	8.334	10.420	11.594	13.382
N. Hampshire	9.124	10.199	12.024	13.068	13.135
Florida	10.196	10.442	11.059	12.049	12.735
Kansas	8.362	10.387	10.922	11.801	12.223
Missouri	8.365	9.354	9.707	10.427	12.079
Montana	—	—	10.717	12.160	11.924
Texas	6.83[illegible]	7.593	8.537	9.686	11.822
Iowa	7.131	7.385	9.891	10.589	11.659
Idaho	6.344	7.579	9.735	10.868	11.469
Delaware	11.193	12.075	11.394	10.097	11.370
W. Virginia	7.195	8.204	10.478	10.665	11.058
N. Mexico	7.912	7.413	9.184	9.460	11.011
Oklahoma	7.312	7.919	9.816	10.641	10.785
Indiana	7.634	8.109	8.915	10.303	10.665
Georgia	8.610	8.688	9.160	9.838	10.476
Kentucky	9.766	9.031	8.807	9.742	10.353
Nebraska	6.315	6.606	7.601	8.725	10.158
Mississippi	—	4.750	9.295	9.174	9.402
Alabama	7.129	7.935	8.875	9.549	9.300
N. Dakota	—	—	—	7.821	9.200
Tennessee	8.368	8.439	8.091	9.217	9.165
N. Carolina	7.842	7.789	8.231	9.358	9.069
S. Carolina	—	7.907	8.175	8.702	8.865
S. Dakota	5.917	7.163	7.684	8.526	8.500
Arkansas	—	12.833	12.375	—	8.411
Maine	5.261	5.251	6.111	7.026	7.849
Wyoming	—	—	—	—	—
Arizona	—	—	—	—	—
U.S. Total	8.947	9.856	10.841	12.291	13.539

Average Cost of Finished Residential Lot/ft^2 1976-1980

State	1976	1977	1978	1979	1980
Alabama	$0.48	$0.47	$0.48	$0.55	$0.55
Alaska	—	—	2.27	2.27	3.00
Arizona	0.27	0.25	0.91	1.15	1.28
Arkansas	0.46	1.13	0.75	0.71	0.85
California	1.57	1.78	2.07	2.96	3.68
Colorado	0.95	1.09	1.25	1.44	1.70
Connecticut	0.44	0.45	0.49	0.63	0.64
Delaware	0.40	0.42	0.77	0.45	0.45
Wash. D.C.	—	—	—	9.43	11.39
Florida	0.95	0.96	1.02	1.13	1.18
Georgia	0.45	0.47	0.47	0.52	0.57
Hawaii	—	—	—	—	10.38
Idaho	0.50	0.67	0.89	1.07	1.16
Illinois	1.09	1.11	1.42	1.57	1.82
Indiana	0.50	0.52	0.58	0.69	0.74
Iowa	0.75	0.69	0.90	0.97	1.00
Kansas	0.75	0.93	0.96	1.08	1.14
Kentucky	0.87	0.79	0.70	0.78	0.89
Louisiana	0.61	0.65	0.95	1.21	1.34
Maine	0.16	0.12	0.14	0.17	0.19
Maryland	1.07	0.95	0.96	1.16	1.48
Massachusetts	0.35	0.40	0.49	0.48	0.49
Michigan	0.72	0.65	0.73	0.95	0.96
Minnesota	0.48	0.51	0.71	0.87	0.99
Mississippi	0.41	0.47	0.63	0.70	0.74
Missouri	0.79	0.83	0.85	0.89	1.01
Montana	0.78	0.84	0.74	1.06	1.04
Nebraska	0.65	0.71	0.83	0.96	1.13
Nevada	0.55	0.89	1.03	0.76	1.82
New Hampshire	0.25	0.25	0.49	0.51	0.60
New Jersey	0.79	0.84	0.87	0.98	1.11
New Mexico	0.72	0.86	0.96	1.00	1.13
New York	0.73	0.86	0.57	0.70	0.79
N. Carolina	0.34	0.44	0.44	0.48	0.47
N. Dakota	0.42	0.45	0.48	0.53	0.86
Ohio	0.65	0.84	0.95	1.14	1.18
Oklahoma	0.59	0.63	0.80	0.92	1.00
Oregon	0.77	1.02	1.28	1.56	1.75
Pennsylvania	0.46	0.59	0.61	0.73	0.78
Rhode Island	—	0.32	0.36	0.40	0.42
S. Carolina	0.38	0.71	0.63	0.65	0.62
S. Dakota	0.63	0.66	0.53	0.49	0.63
Tennessee	0.62	0.63	0.49	0.59	0.79
Texas	0.69	0.81	0.91	0.96	1.18
Utah	0.87	0.94	1.18	1.39	1.45
Vermont	0.40	0.41	0.55	0.44	0.70
Virginia	0.87	0.80	0.97	1.19	1.42
Washington	0.62	0.70	0.89	1.01	1.25
W. Virginia	0.50	0.55	0.64	0.73	0.67
Wisconsin	0.57	0.62	0.78	0.88	0.92
Wyoming		1.00	NA	NA	1.80
U.S. Total	0.77	0.80	0.87	0.95	1.05

Source: Homer Hoyt Institute 1981.

Table E-3. Land Price Index and Cost/ft^2 of Residential Land ($)

Land Price Index

Yr	Month	National	North East	North Central	South	West
1979-	1	114.6	104.7	119.5	109.2	119.3
	2	116.3	104.6	121.4	111.8	120.8
	3	116.6	105.4	122.5	112.5	122.1
	4	117.9	104.2	123.9	113.8	123.7
	5	119.2	104.8	123.8	114.6	124.9
	6	120.3	105.7	125.3	115.8	125.5
	7	121.3	104.1	126.1	118.6	127.2
	8	123.9	104.6	127.4	122.3	129.2
	9	125.4	106.8	127.7	125.4	130.3
	10	126.2	107.0	128.9	124.0	130.2
	11	126.9	107.4	130.9	126.3	130.9
	12	128.5	107.0	133.5	127.8	132.1
1980-	1	130.9	106.9	134.2	130.4	134.5
	2	130.7	107.6	135.6	130.0	137.5
	3	133.2	107.5	138.0	131.9	138.8
	4	134.7	105.8	138.0	133.6	140.6
	5	137.7	106.8	139.8	138.7	145.0
	6	139.2	106.0	142.3	139.2	146.2
	7	141.7	107.9	143.5	142.1	148.9
	8	142.7	108.6	144.8	142.4	151.2
	9	144.5	106.8	144.7	144.2	152.9
	10	144.4	106.0	145.2	145.4	153.8
	11	144.9	110.1	147.3	144.4	155.1
	12	144.6	110.7	147.9	144.3	154.9
1981-	1	145.7	113.0	145.7	146.1	156.8
	2	145.6	115.9	145.1	147.7	155.2
	3	145.3	113.3	142.0	146.4	154.2

FOOTNOTE: Data for previous years and by region is available upon request

Cost Per Square Foot of Residential Land (in dollars)

Source	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Home Owners Warranty Corp	n/a	n/a	n/a	n/a	n/a	0.78	0.77	0.80	0.87	0.95	1.05
Bureau of the Census (C 25)	n/a	n/a	n/a	n/a	0.50	0.50	0.76	0.76	0.85	1.04	1.19
FHA 203(b) (New Homes)	0.92	1.04	1.32	1.24	1.34	1.15	1.07	1.07	1.38	1.63	2.07
FHA 203(b) (Existing Homes)	0.66	0.64	0.70	0.75	0.74	0.91	0.92	0.92	1.16	1.25	1.71
FHA 245 (New Homes)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1.65	1.99
FHA 245 (Existing Homes)	n/a	n/a	447.	497.	536.	712.	724.	744.	1,024.	1,050.	1,180.
Farm (Rural Residential)*	n/a	n/a	316.	622.	448.	1,110.	751.	948.	624.	1,598.	1,215.
Farm (All Other Residential Uses)*	244.	358.	266.	292.	340.	438.	528.	654.	591.	618.	779.

*Cost per acre. n/a—Not available

Source: Homer Hoyt Institute 1981.

APPENDIX F

NATURAL RESOURCES AND PHYSICAL CONDITIONS PERTINENT TO SOLAR PONDS: WATER

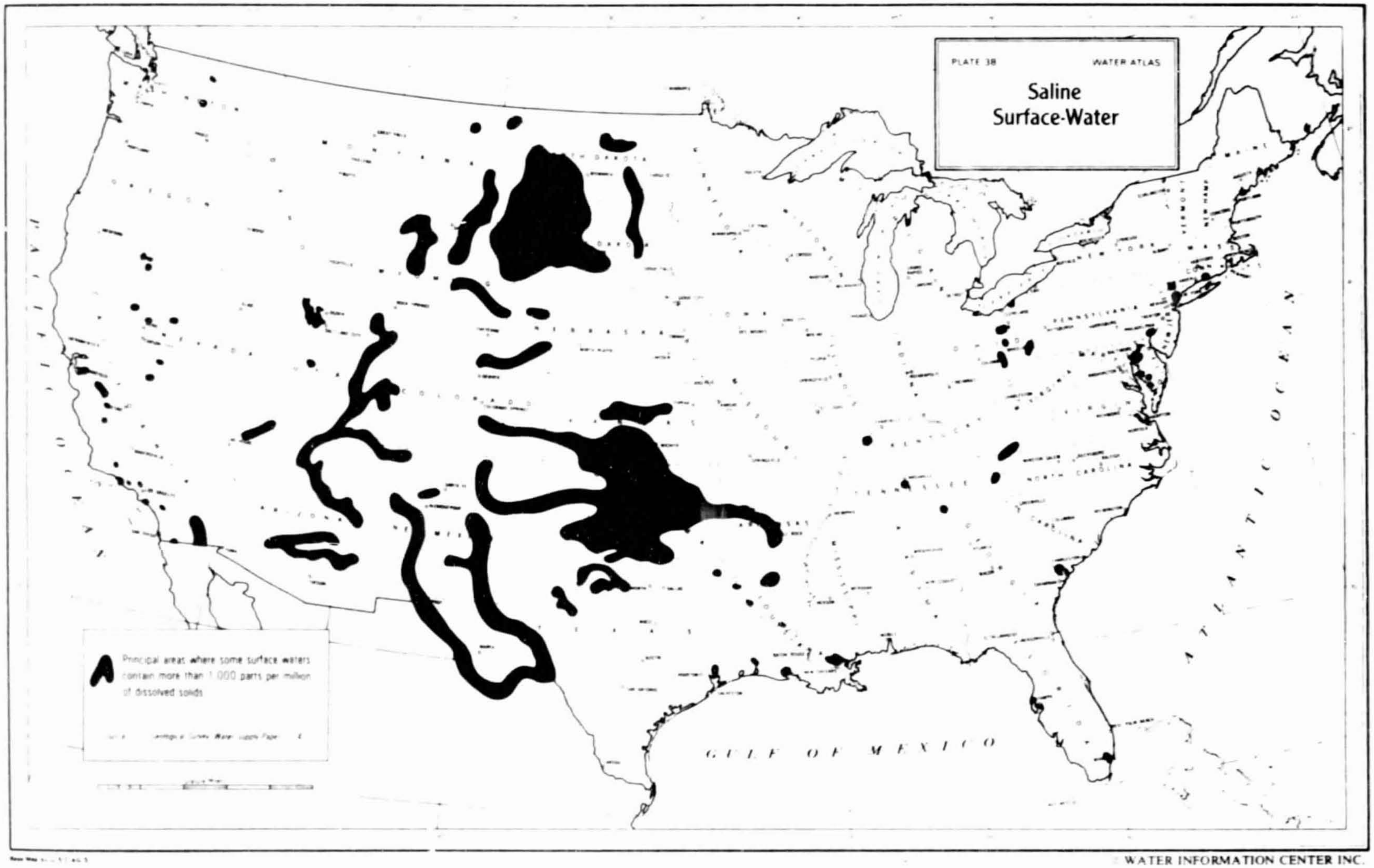

Figure F-1. Saline Surface Water Containing More Than 1000 ppm Dissolved Solids
(Source: Geraghty, et al, 1973)

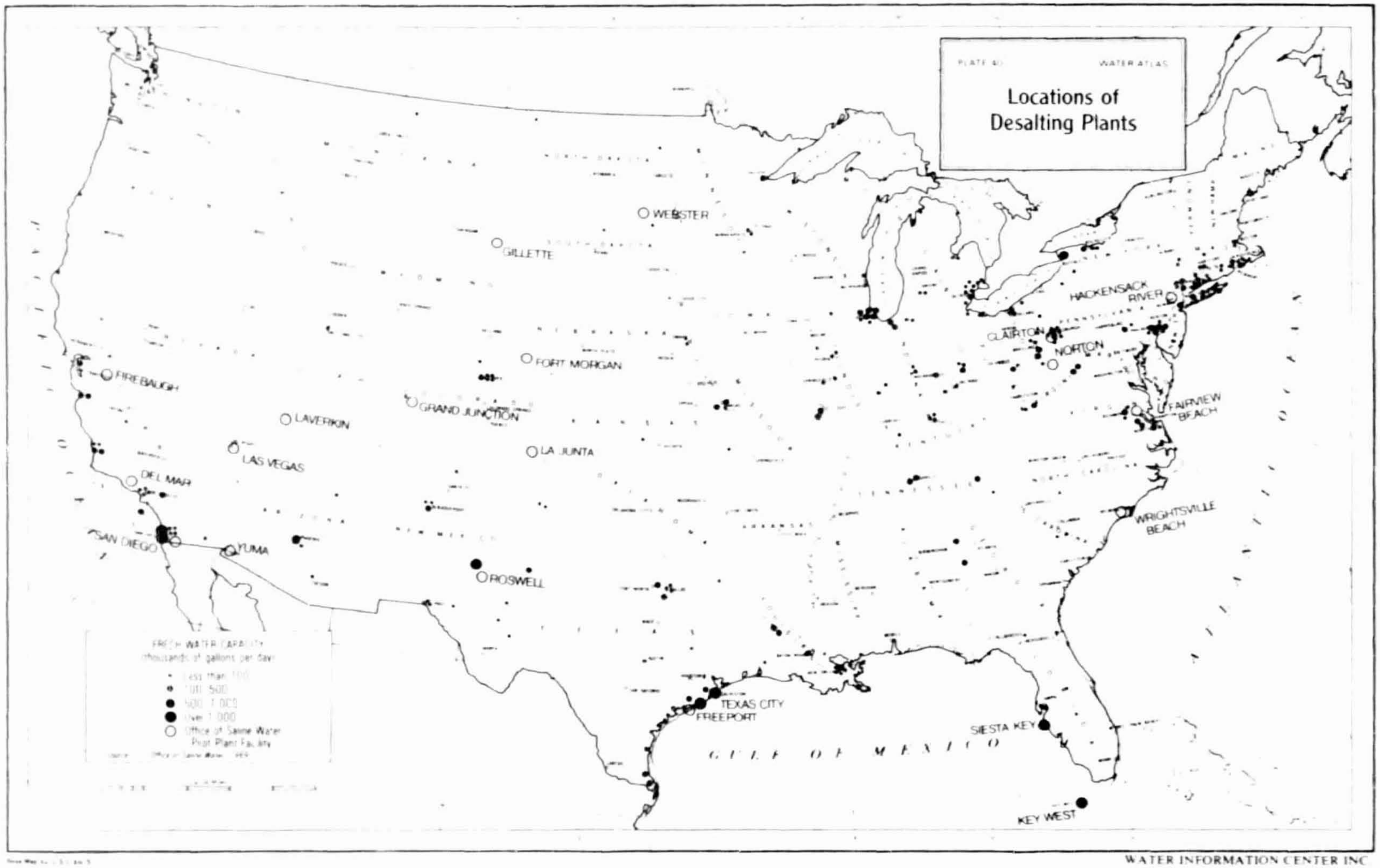

Figure F-2. Locations of Desalting Plants (Source: Geraghty, et al, 1973)

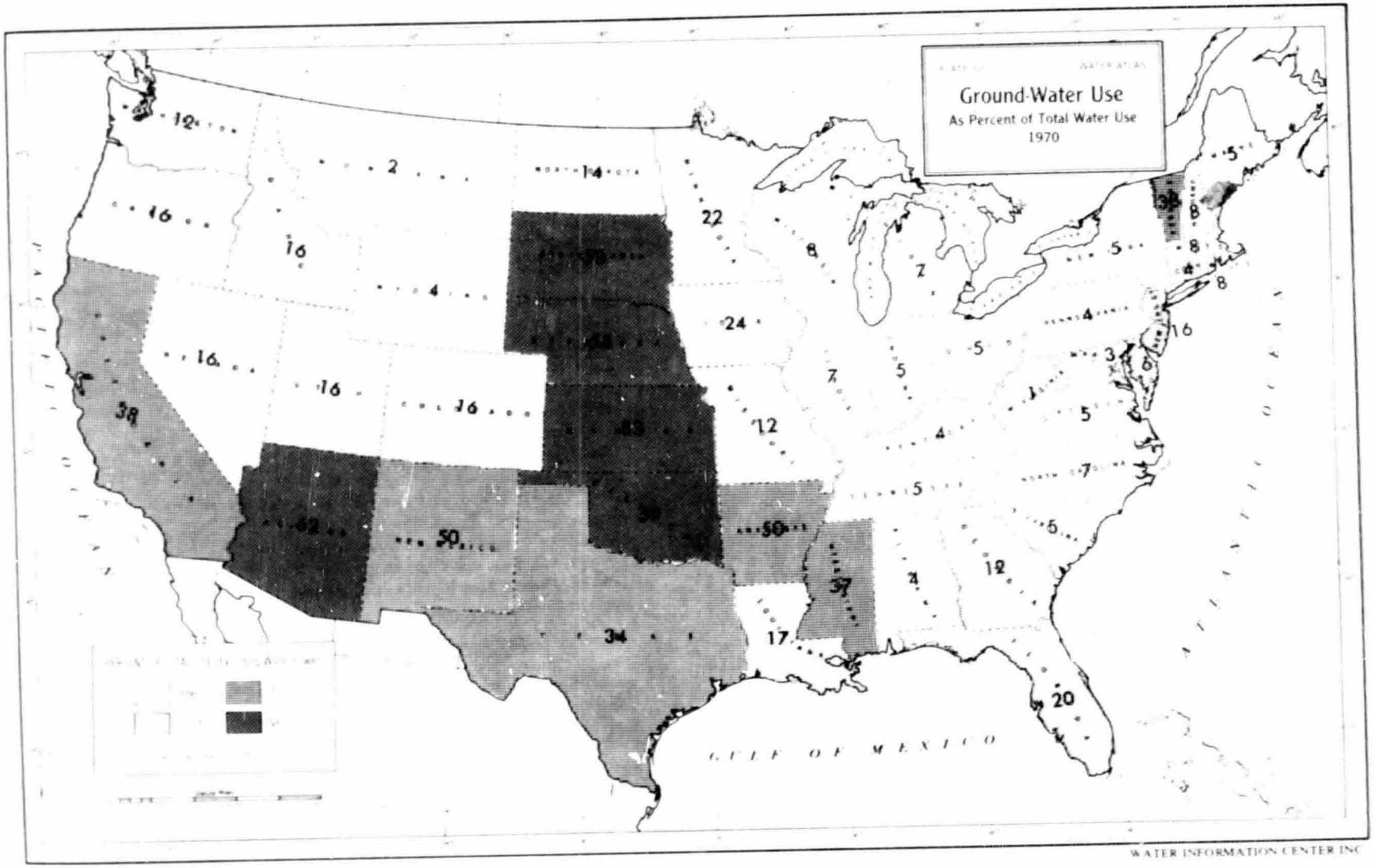

Figure F-3. Groundwater Use as Percent of Total Water Use (Source: Geraghty, et al, 1973)

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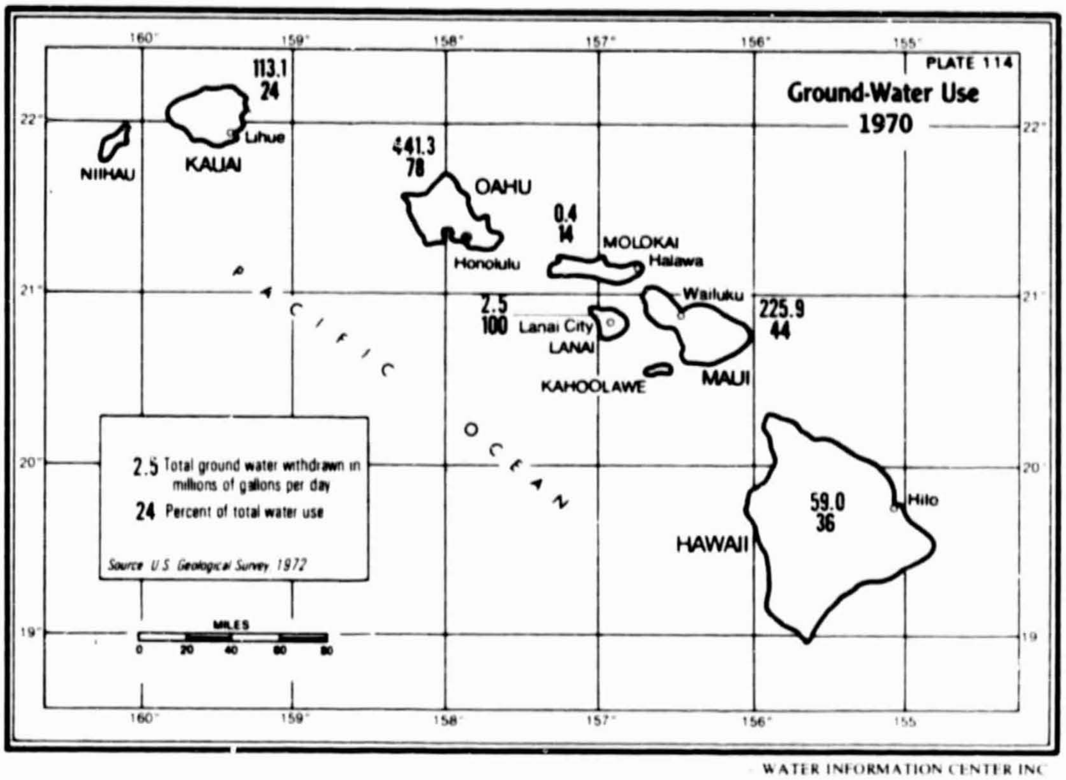

Figure F-4. Groundwater Use in Hawaii (Source; Geraghty, et al, 1973)

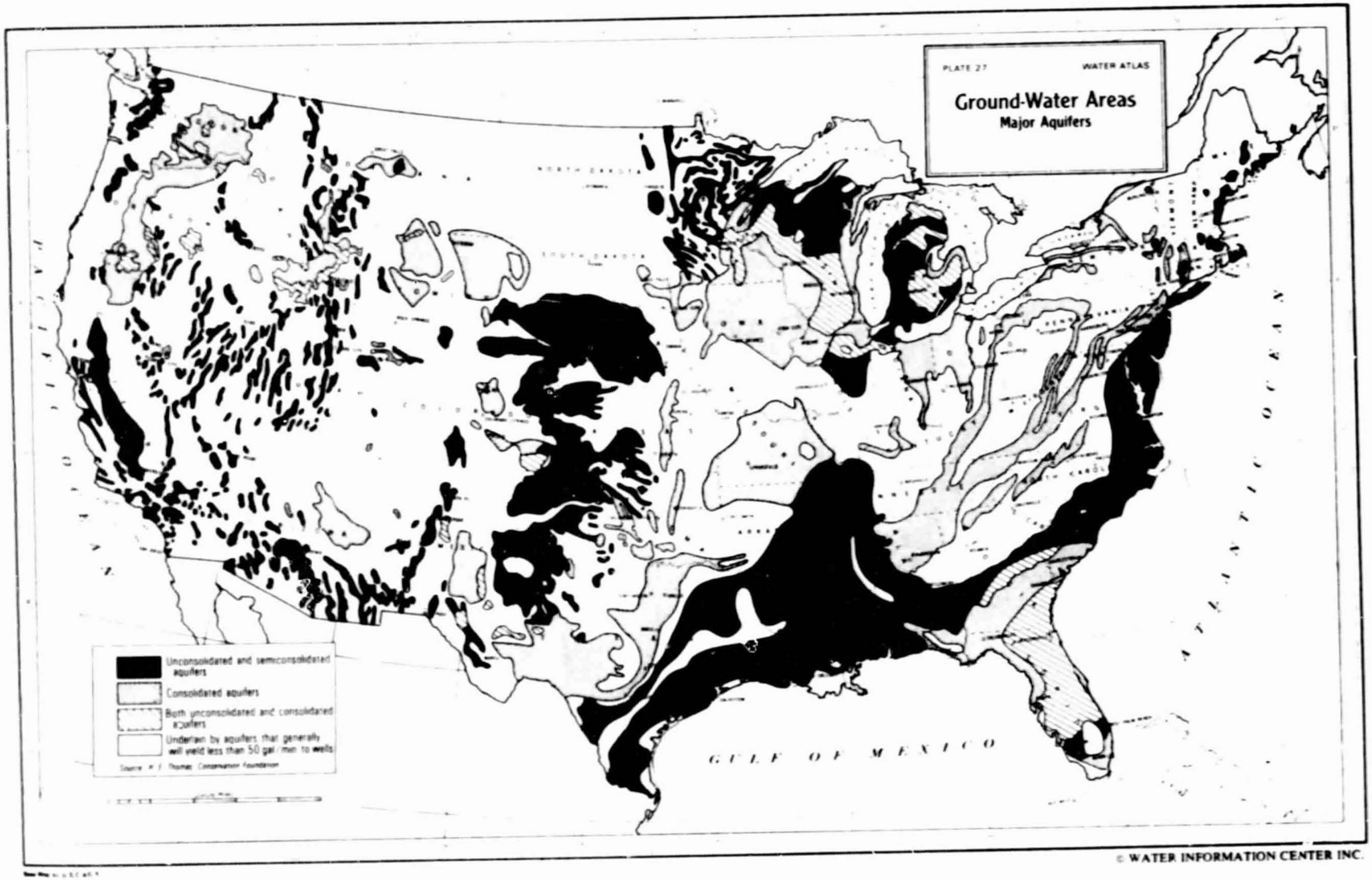

Figure F-5. Major Aquifers of the Conterminous United States (Source: Geraghty, et al, 1973)

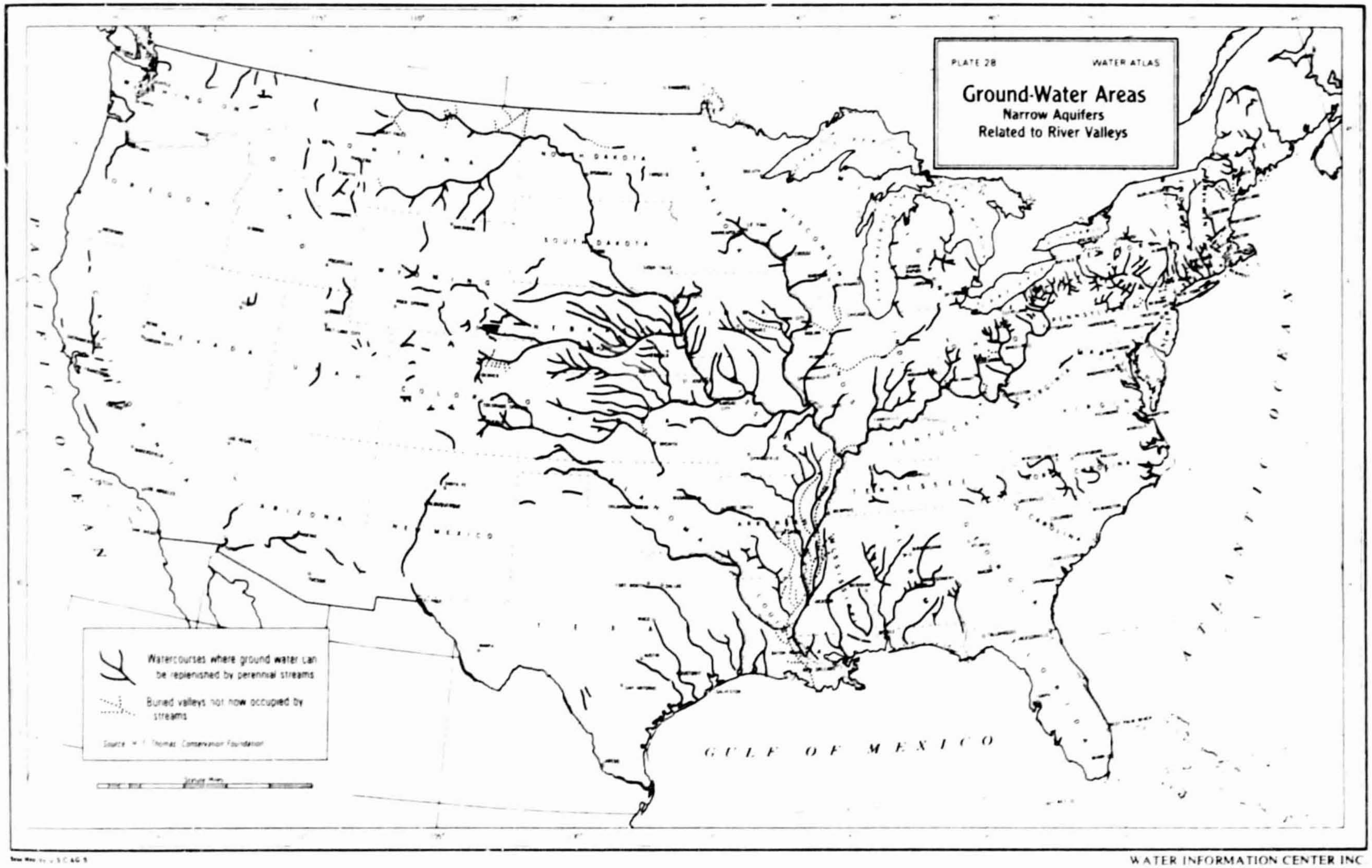

Figure F-8. Narrow Aquifers Related to River Valleys (Source: Geraghty, et al, 1973)

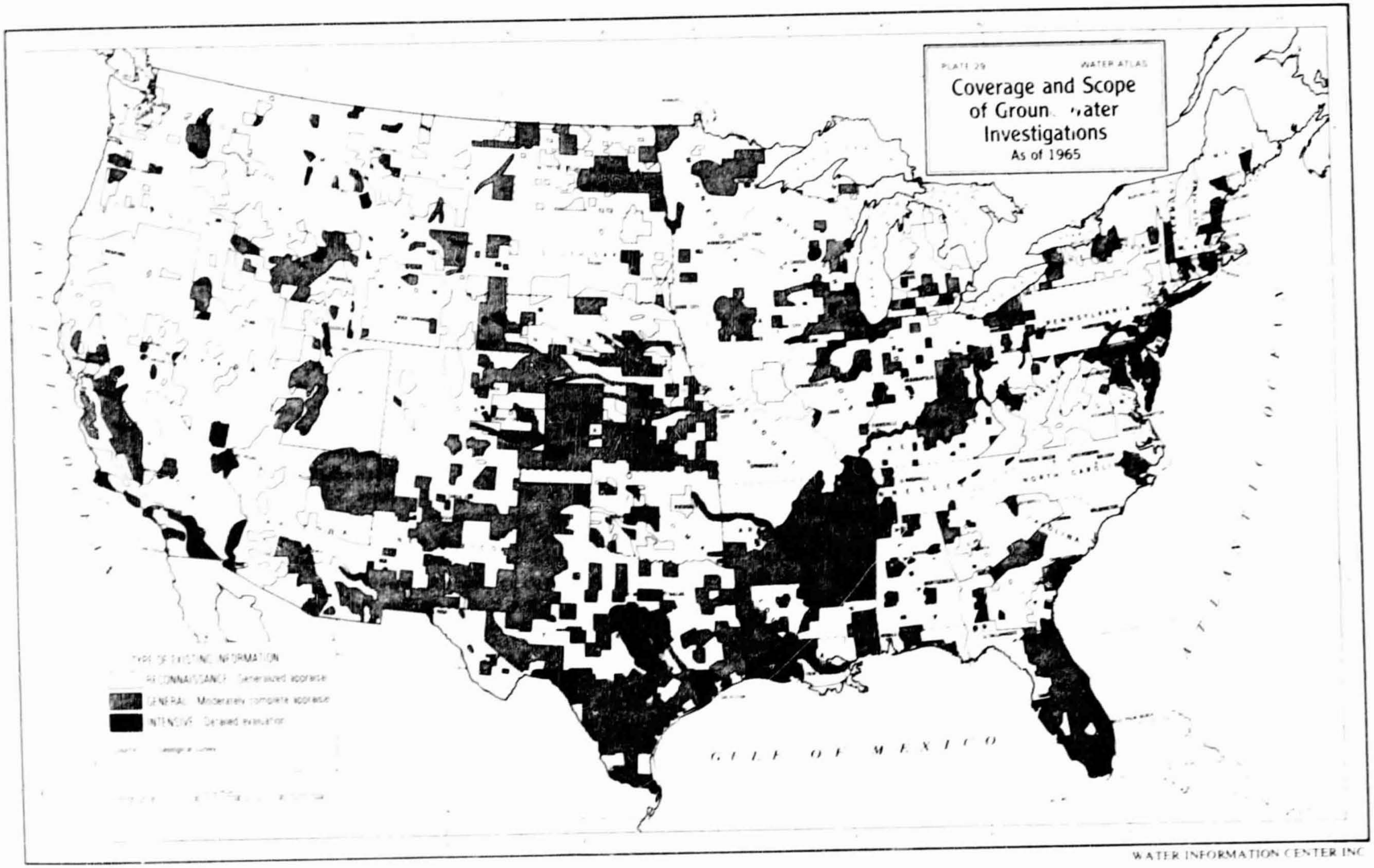

Figure F-9. Coverage and Scope of Groundwater Investigation (Source: Geraghty, et al, 1973

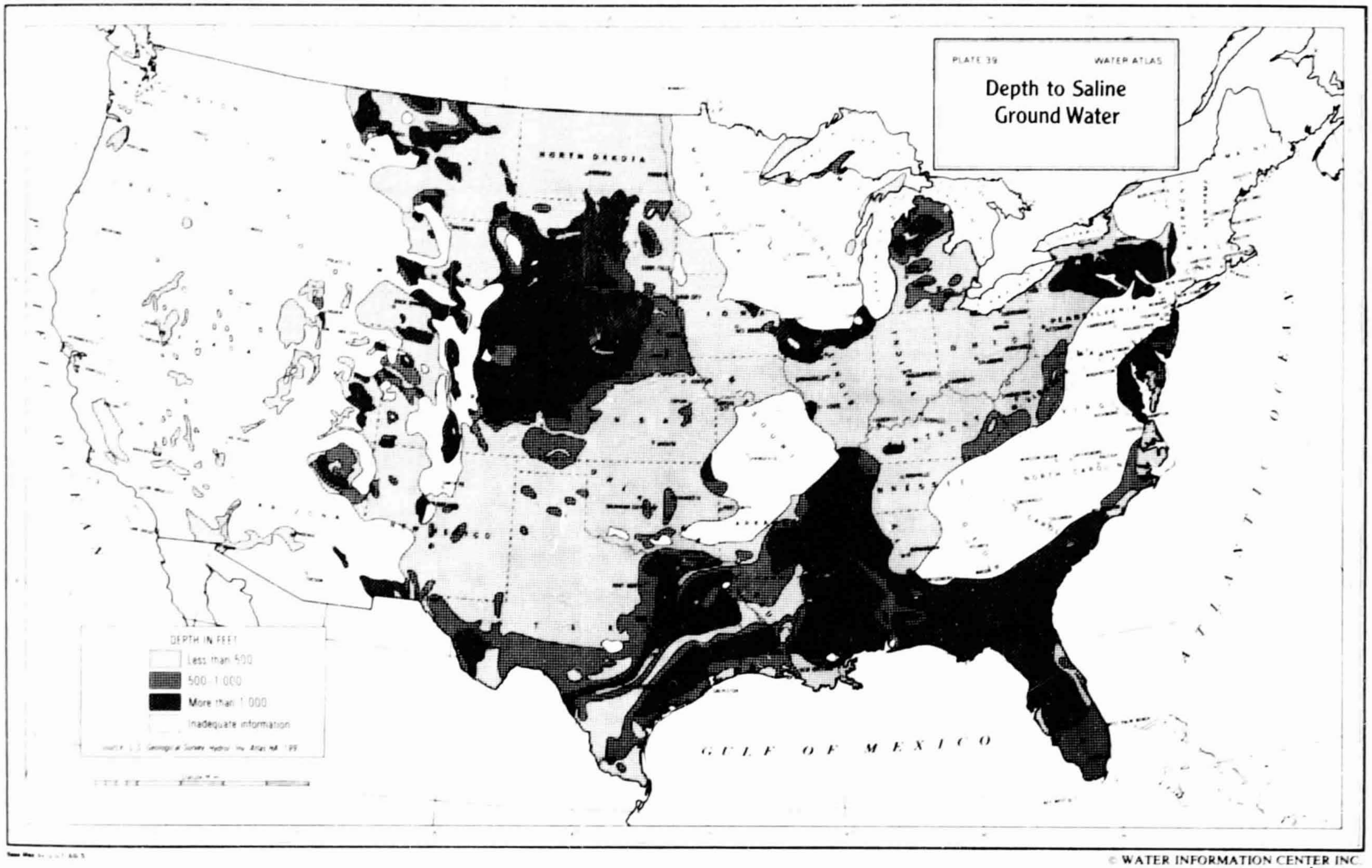

Figure F-10. Depth to Saline Groundwater (Sour‹ ›: Geraghty, et al, 1973)

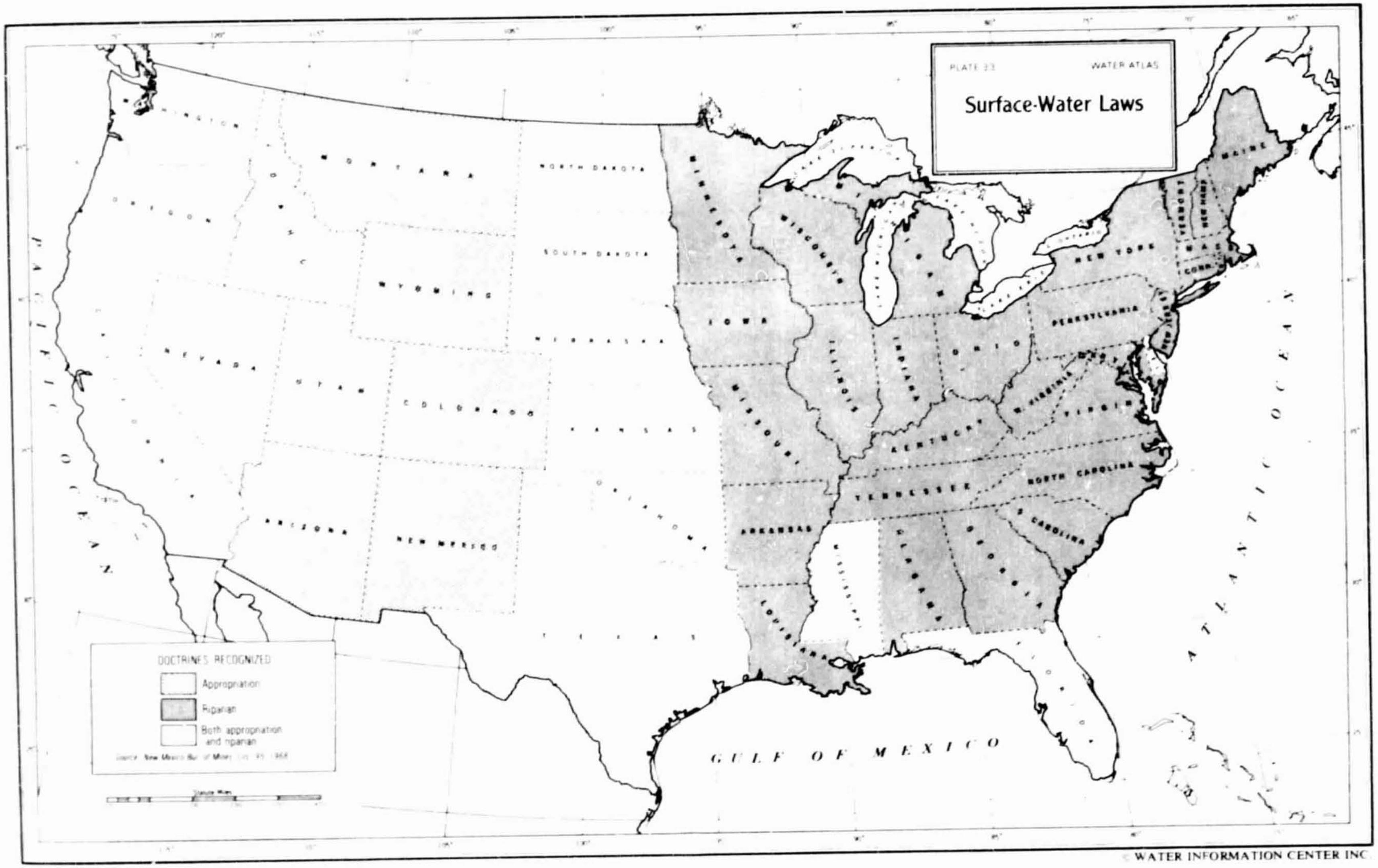

Figure F-11. Summary of Surface-Water Laws (Source: Geraghty, et al, 1973)

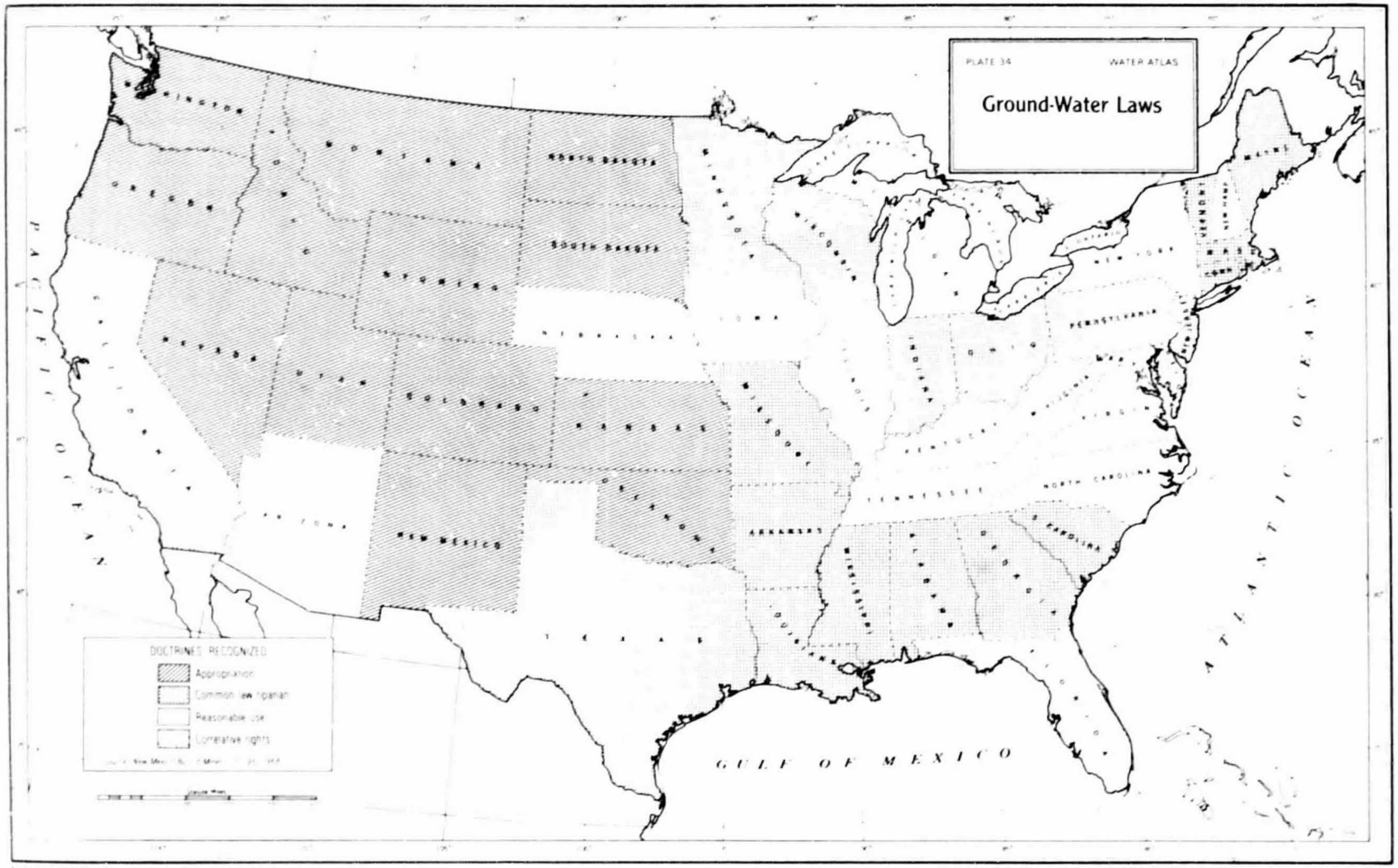

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Figure F-12. Summary of Groundwater Laws (Source: Geraghty, et al, 1973)

APPENDIX G

METEOROLOGICAL AND HYDROGEOLOGICAL CONDITIONS

G.1 METEOROLOGICAL AND HYDROGEOLOGICAL CONDITIONS: AMBIENT TEMPERATURE

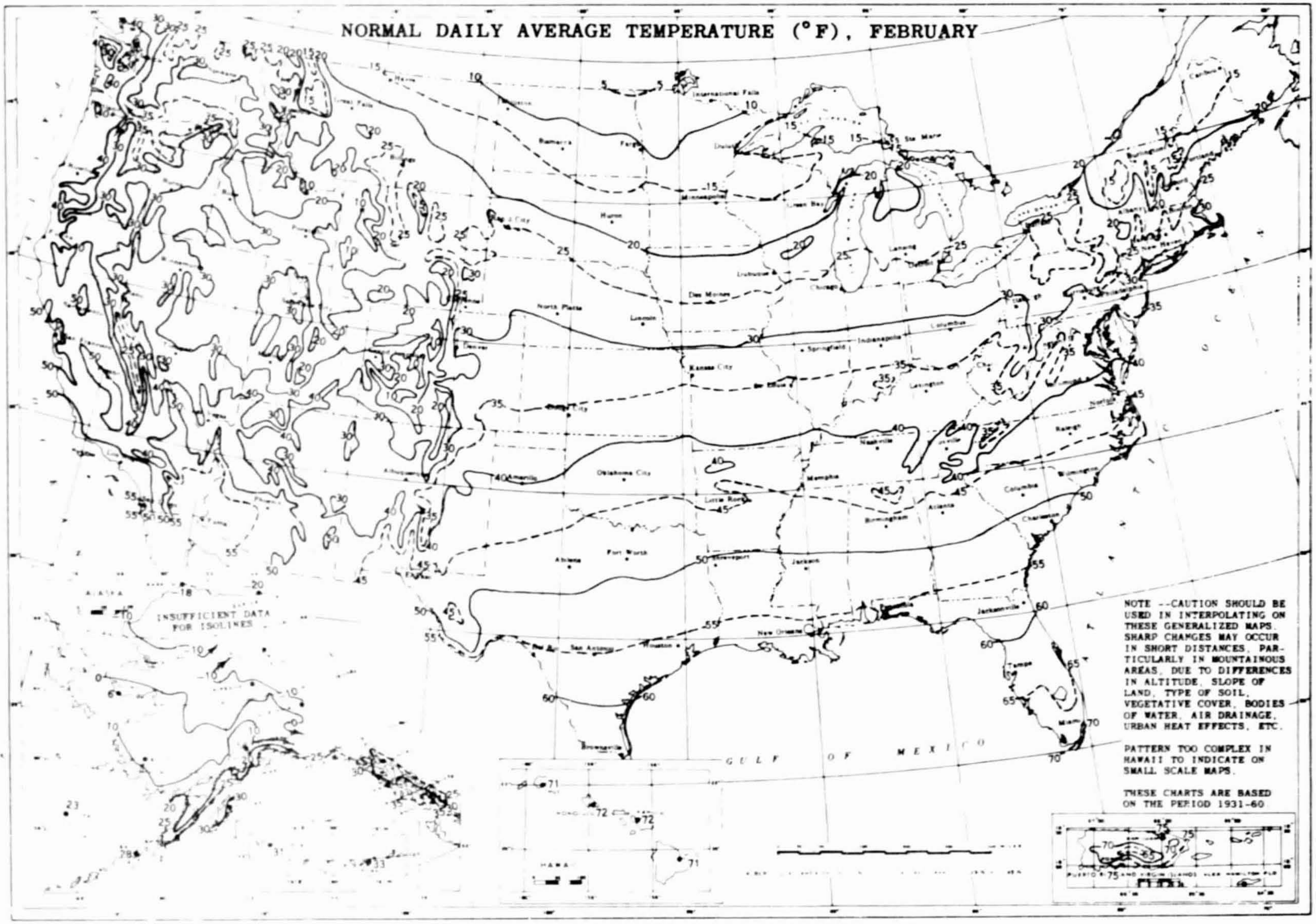

Figure G-2. Ambient Temperature (°F), February (Source: U.S. Dept. of Commerce, 1979)

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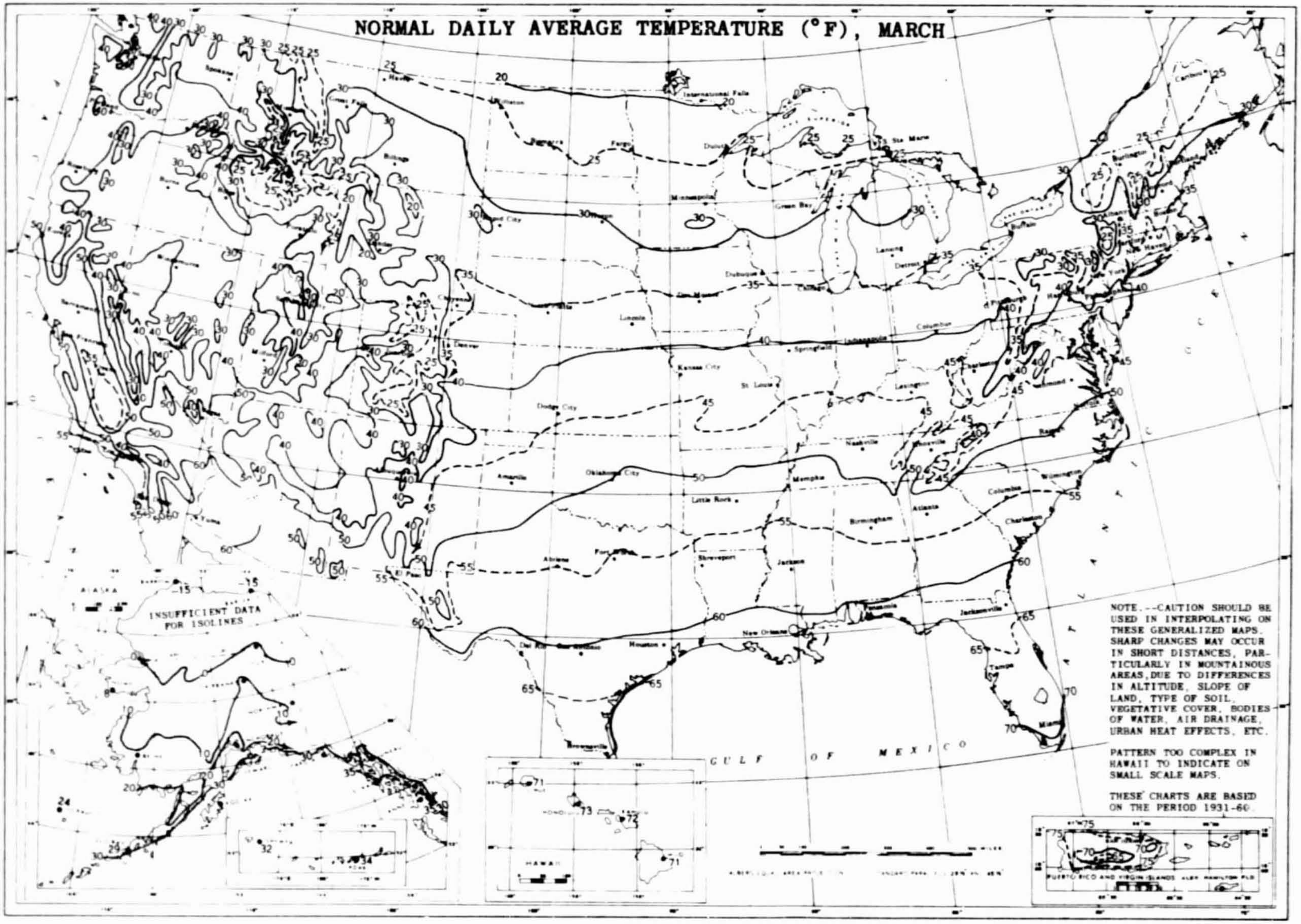

Figure G-3. Ambient Temperature (°F), March (Source: U.S. Dept. of Commerce, 1979)

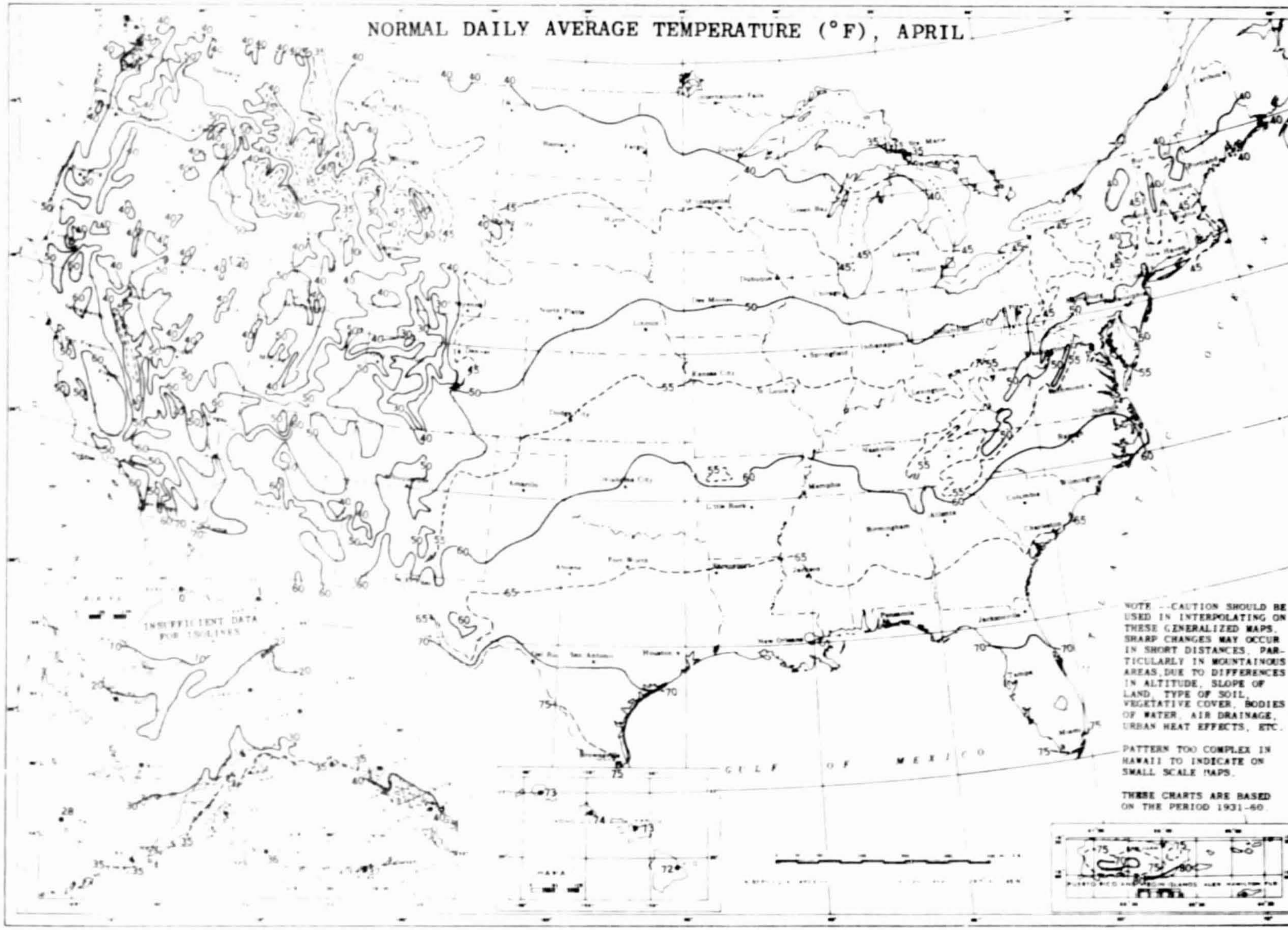

Figure G-4. Ambient Temperature (°F), April (Source: U.S. Dept. of Commerce, 1979)

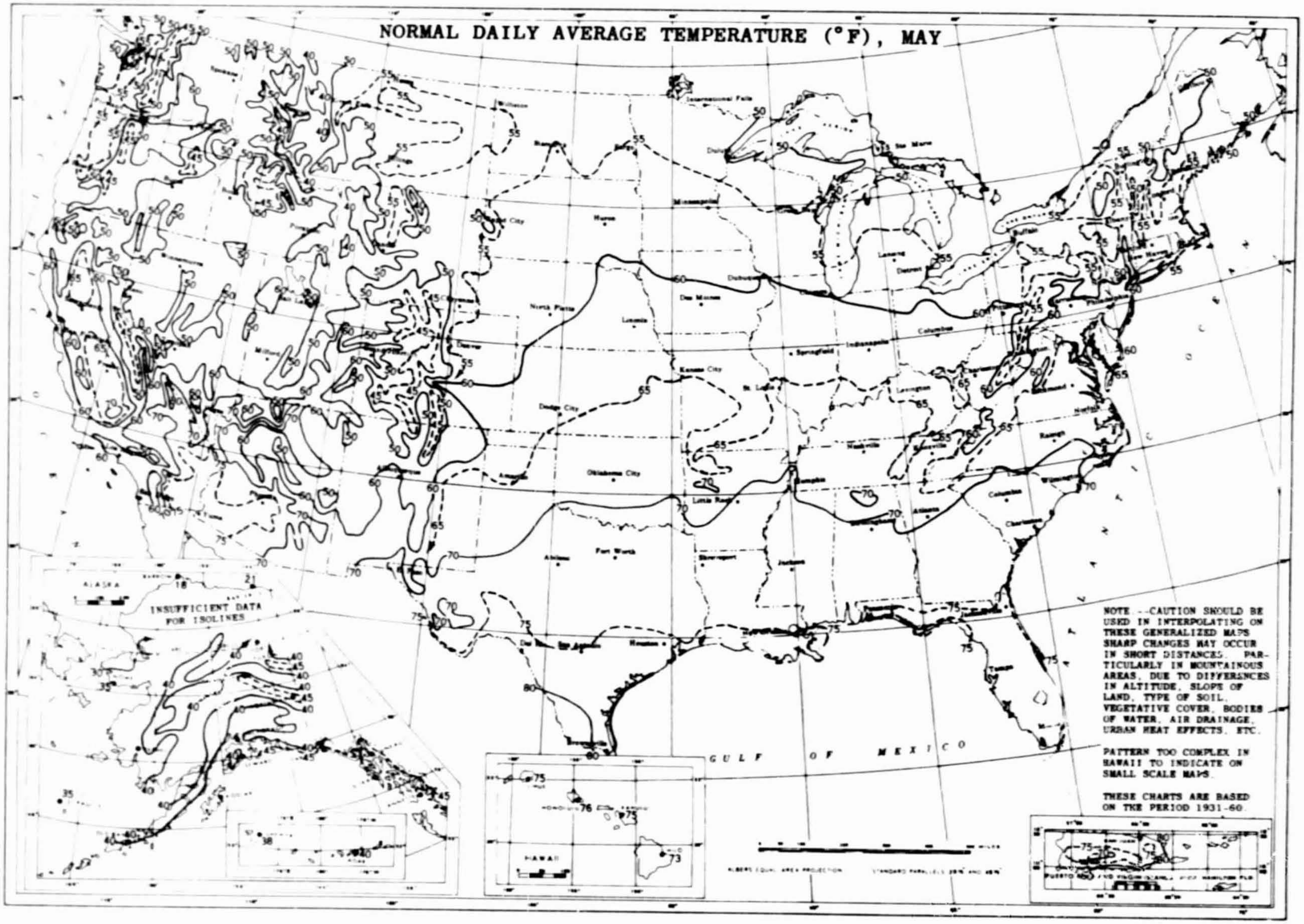

Figure G-5. Ambient Temperature (°F), May (Source: U.S. Dept. of Commerce, 1979)

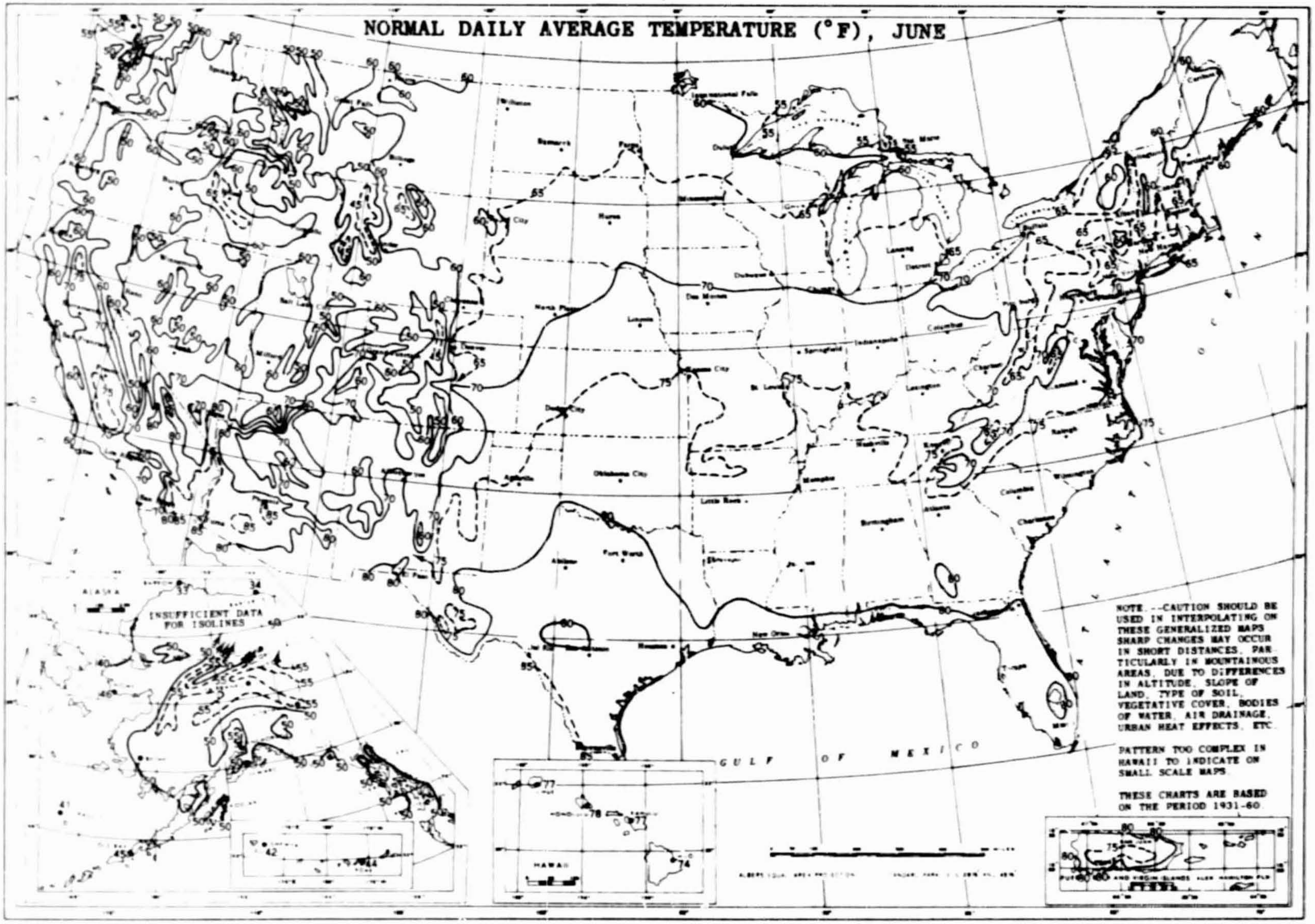

Figure G-6. Ambient Temperature (°F), June (Source: U.S. Dept. of Commerce, 1979)

Figure G-7. Ambient Temperature (°F), July (Source: U.S. Dept. of Commerce, 1979)

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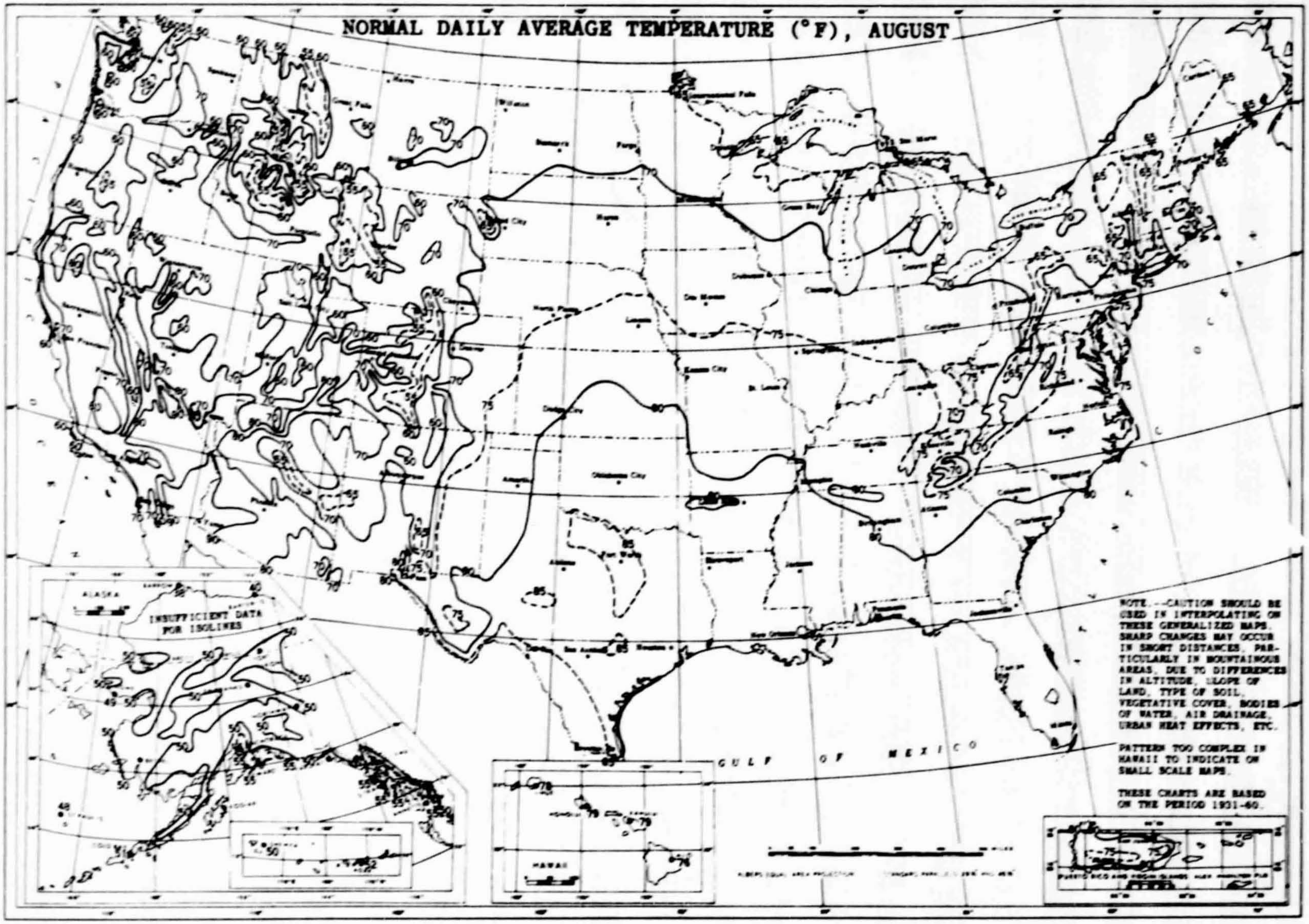

Figure G-8. Ambient Temperature (°F), August (Source: U.S. Dept. of Commerce, 1979)

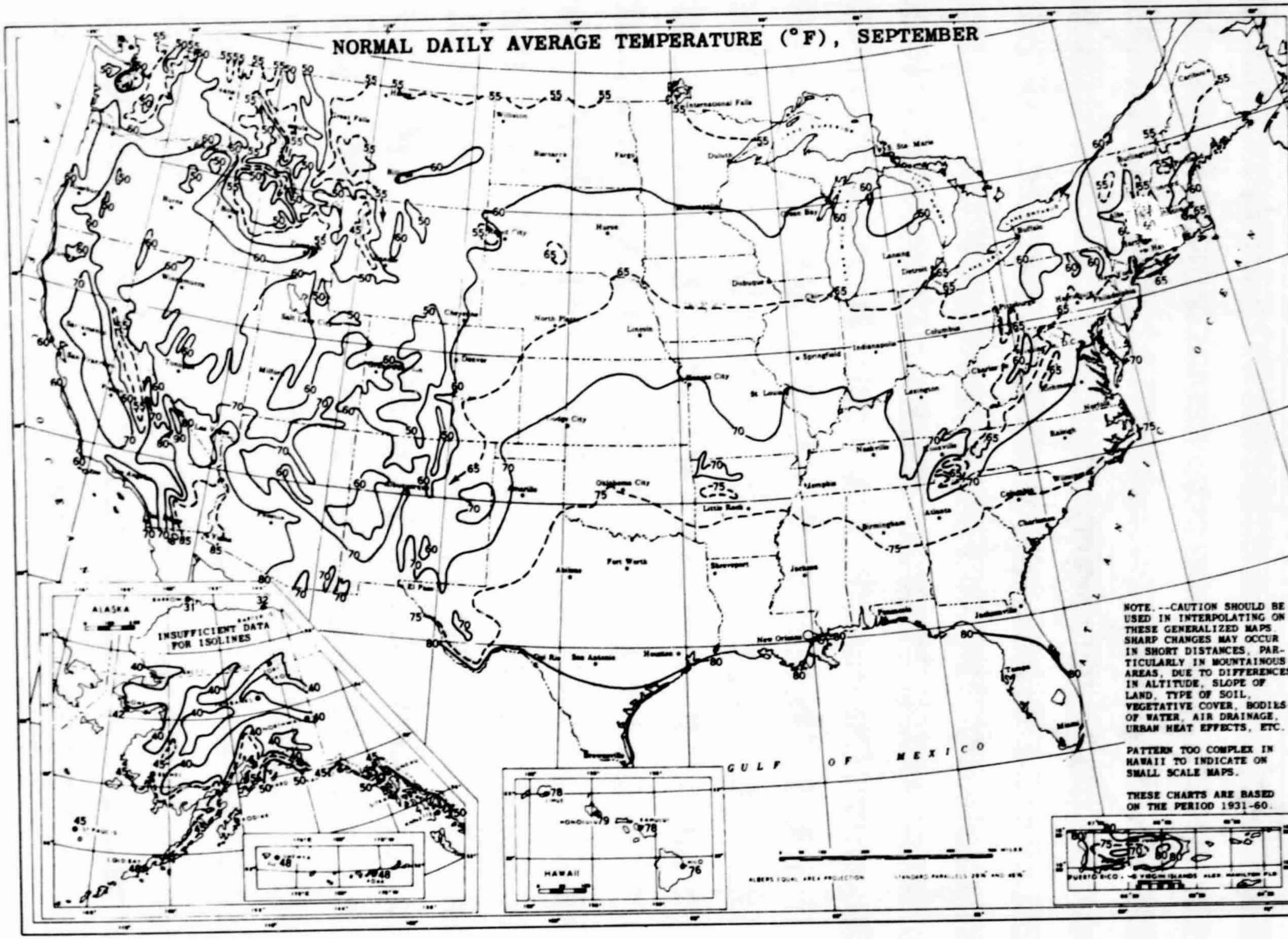

Figure G-9. Ambient Temperature (°F), September (Source: U.S. Dept. of Commerce, 1979)

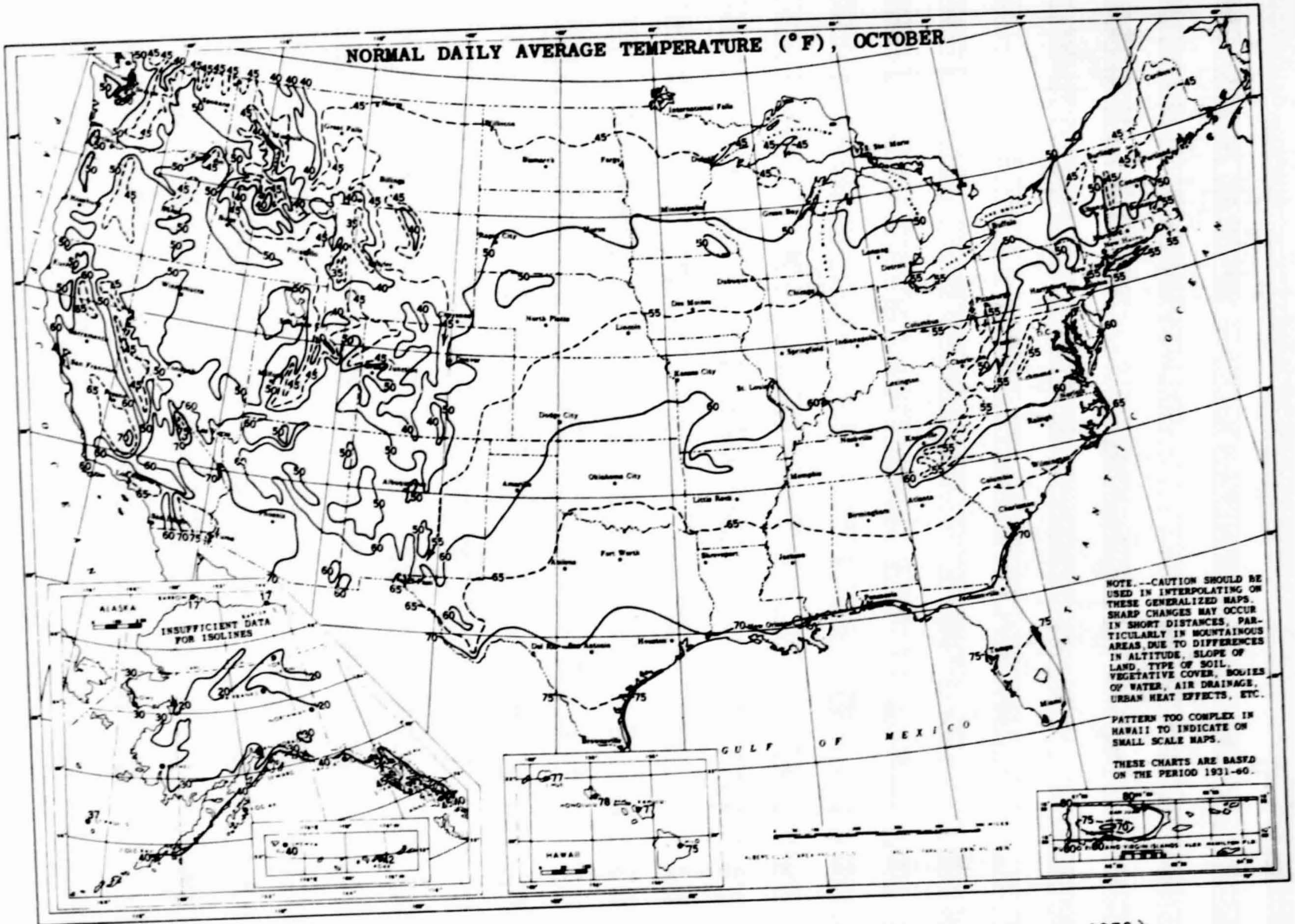

Figure G-10. Ambient Temperature (°F), October (Source: U.S. Dept. of Commerce, 1979)

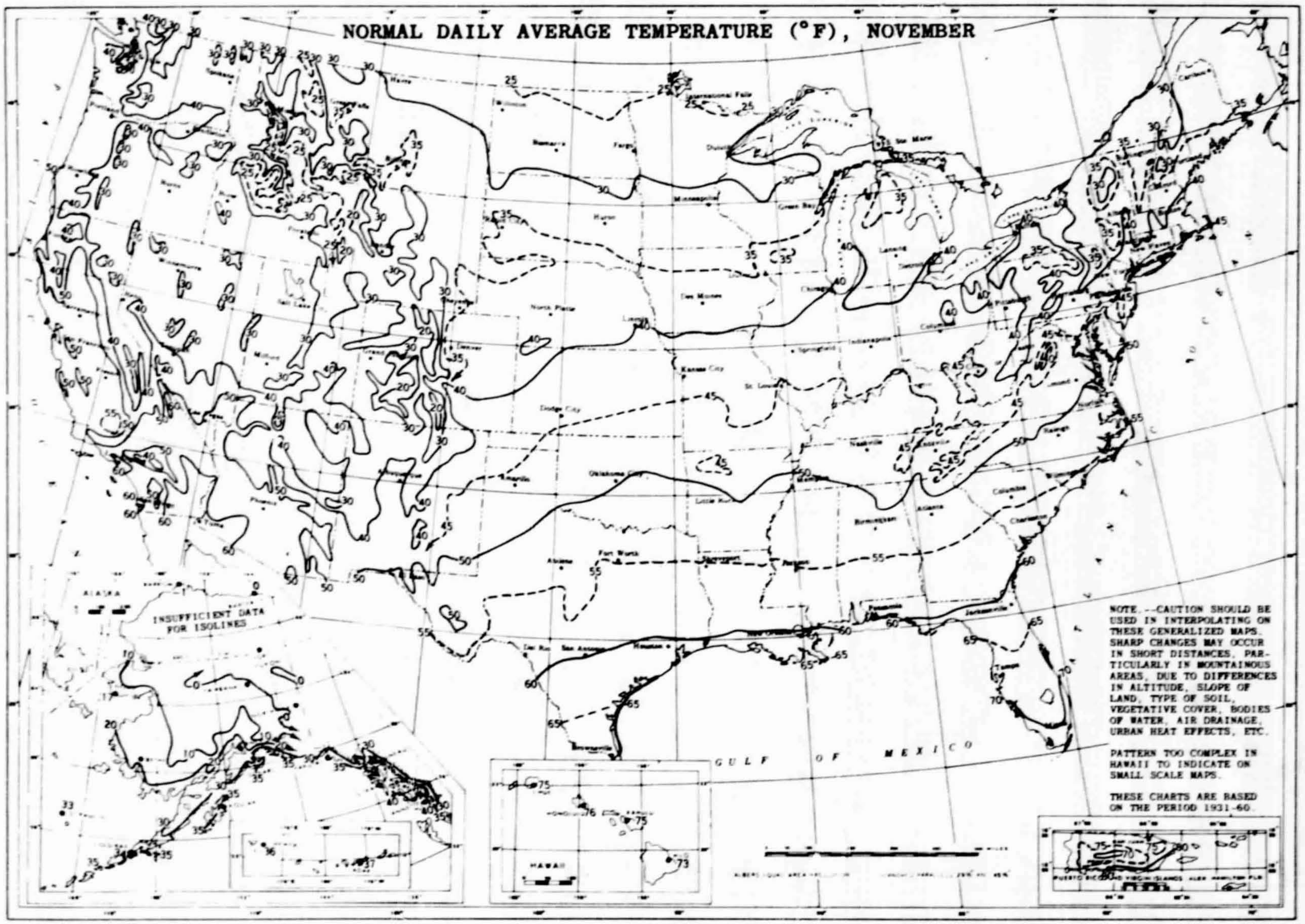

Figure G-11. Ambient Temperature (°F), November (Source: U.S. Dept. of Commerce, 1979)

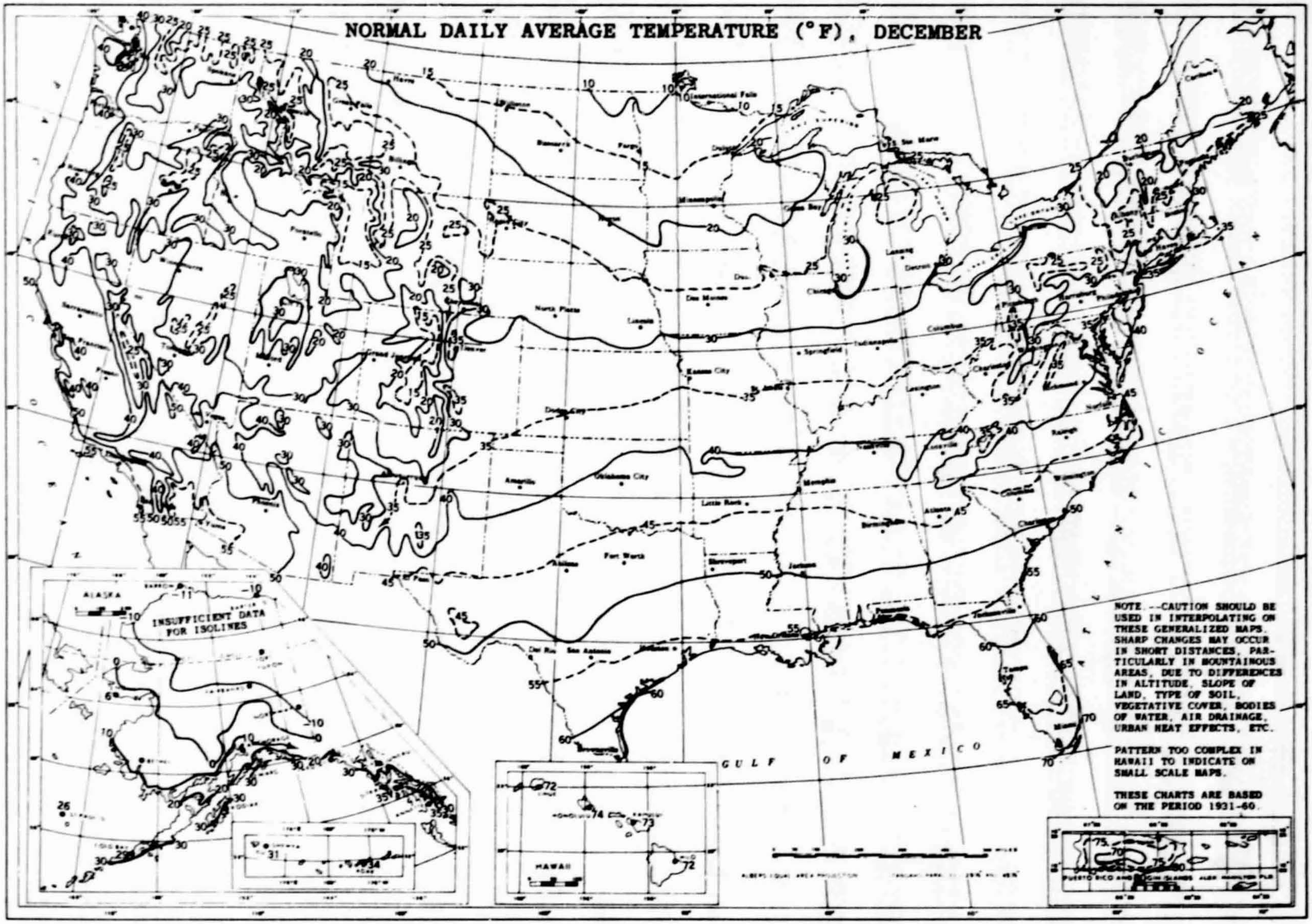

Figure G-12. Ambient Temperature (°F), December (Source: U.S. Dept. of Commerce, 1979)

G.2 METEOROLOGICAL AND HYDROGEOLOGICAL CONDITIONS: EVAPORATION

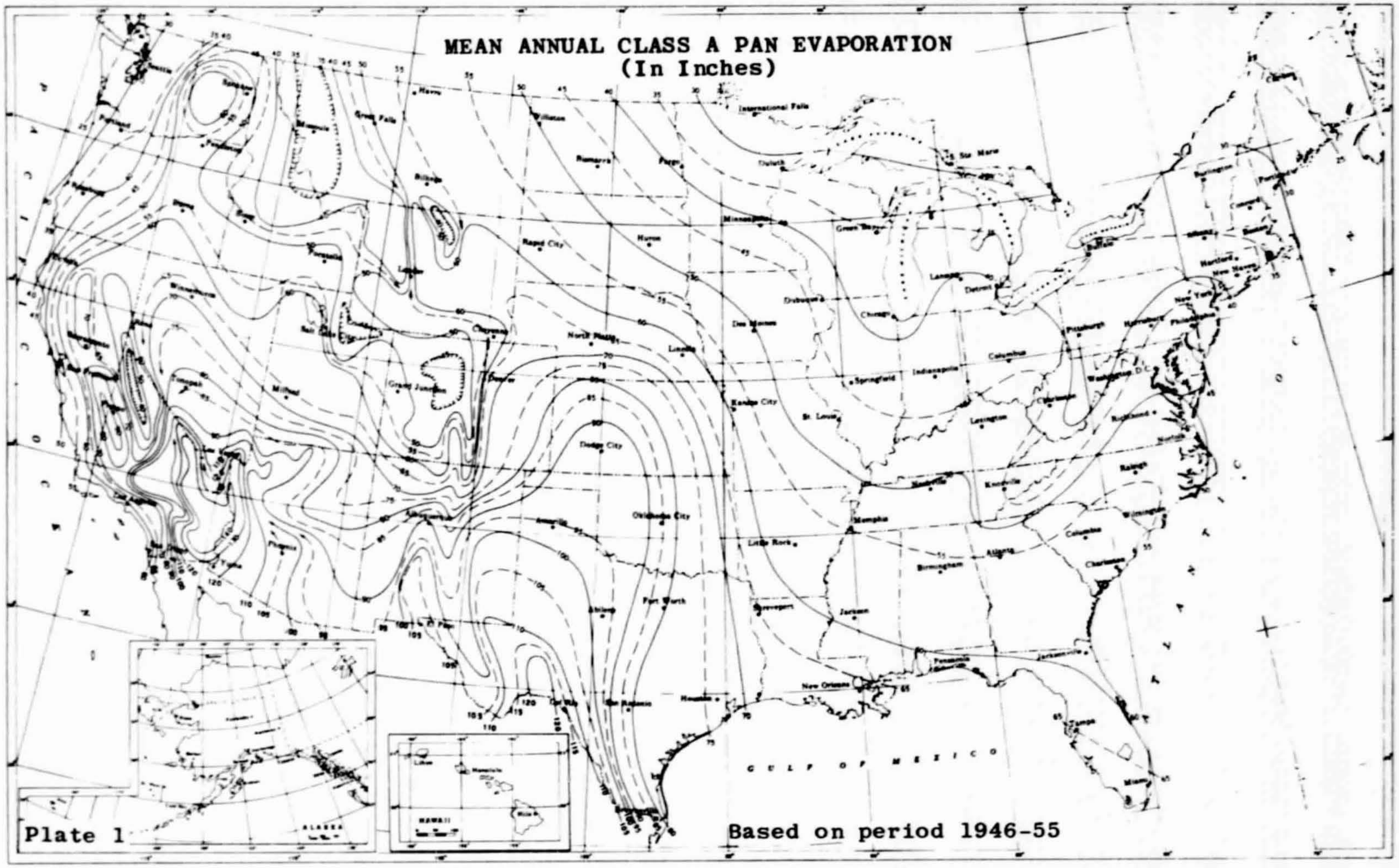

Figure G-13. Mean Annual Class A Pan Evaporation in Inches (Source: U.S. Dept. of Commerce, 1979)

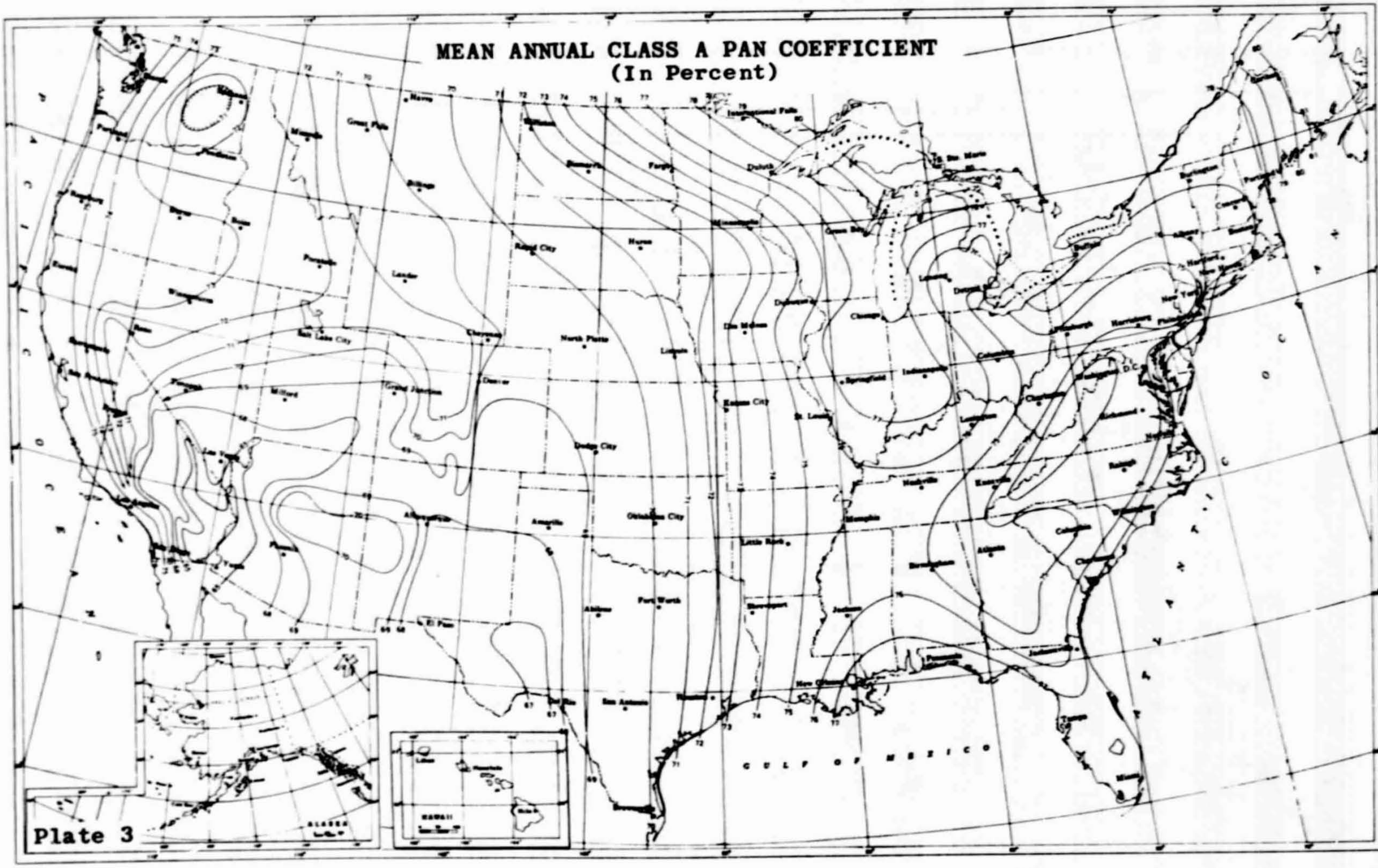

Figure G-14. Mean, Annual Class A Pan Coefficient in Percent (Source: U.S. Dept. of Commerce, 1979)

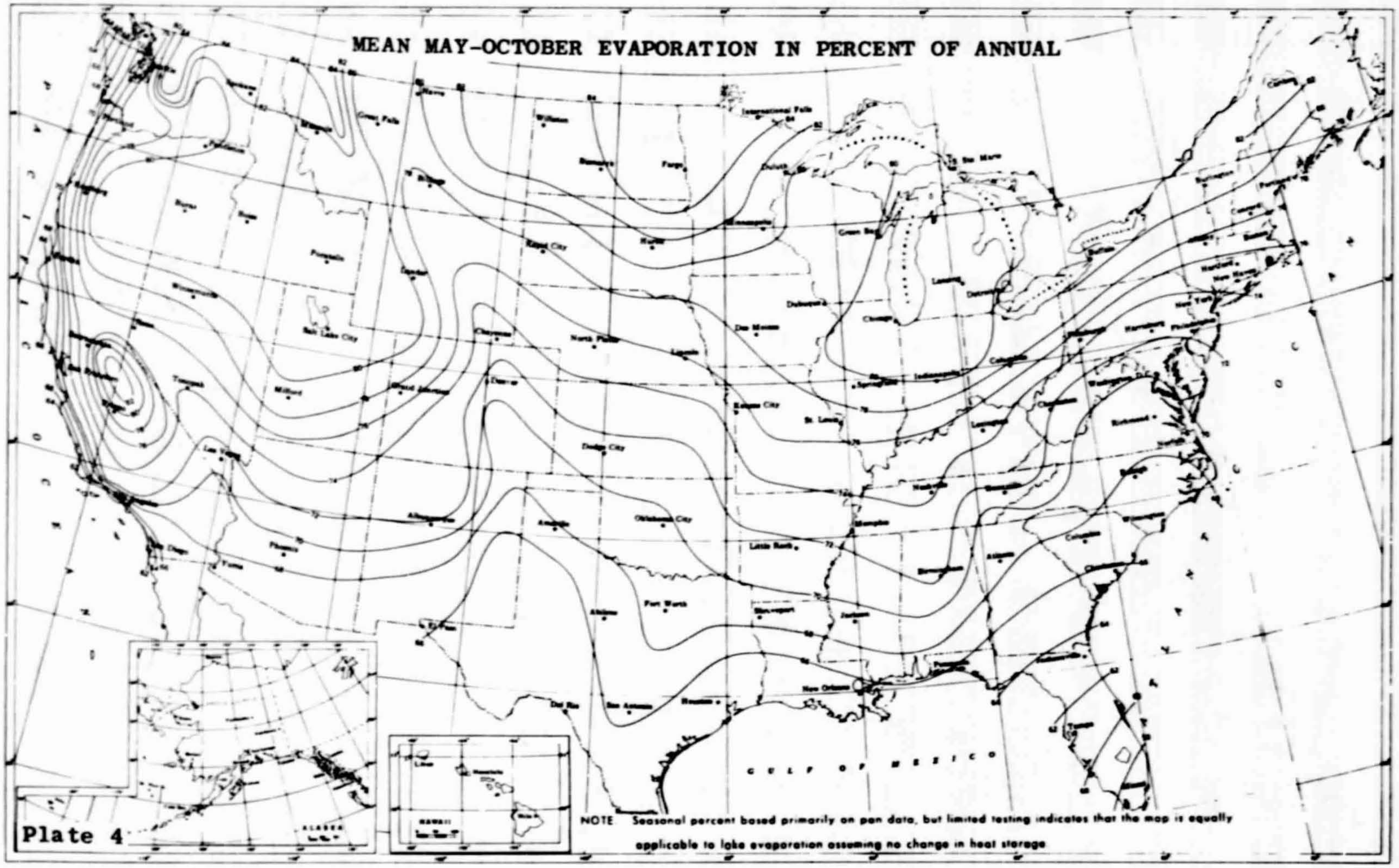

Figure G-15. Mean May-October Evaporation in Percent of Annual (Source: U.S. Dept. of Commerce, 1979)

G.3 METEOROLOGICAL AND HYDROGEOLOGICAL CONDITIONS: PRECIPITATION

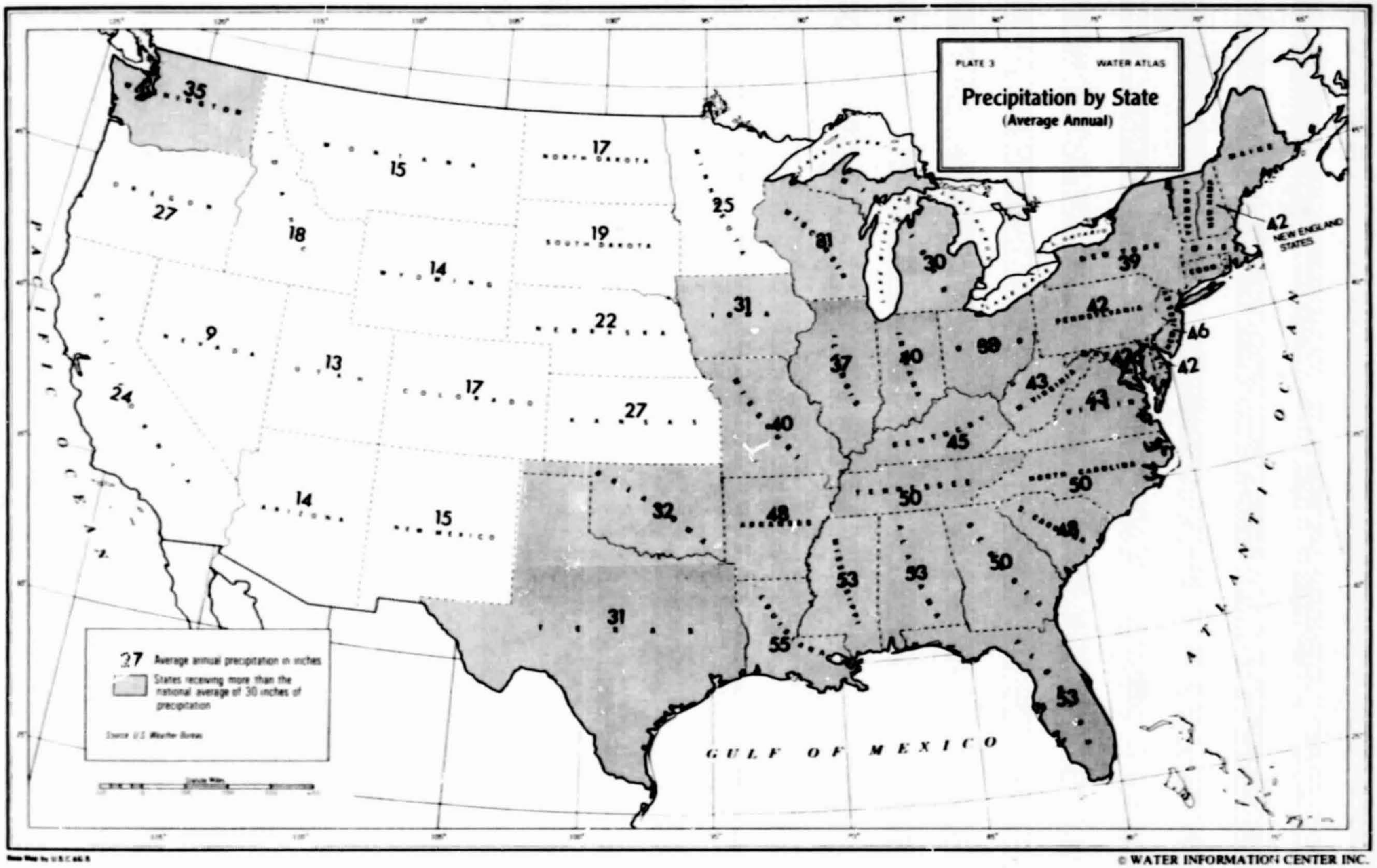

Figure G-16. Statewide Average Annual Precipitation (Source Geraghty, et al, 1973)

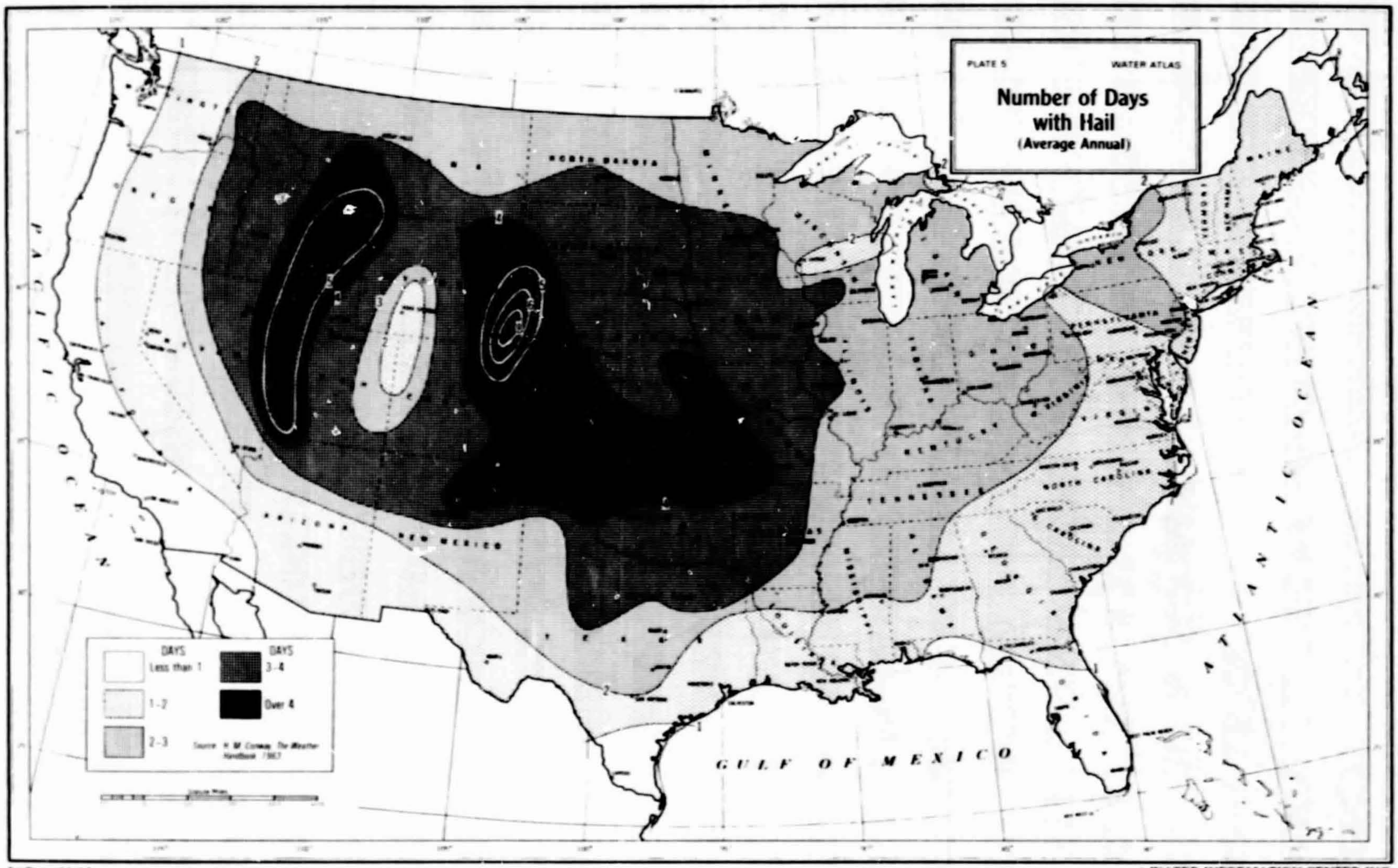

Figure G-17. Average Annual Number of Days With Hail (Source: Geraghty, et al, 1973)

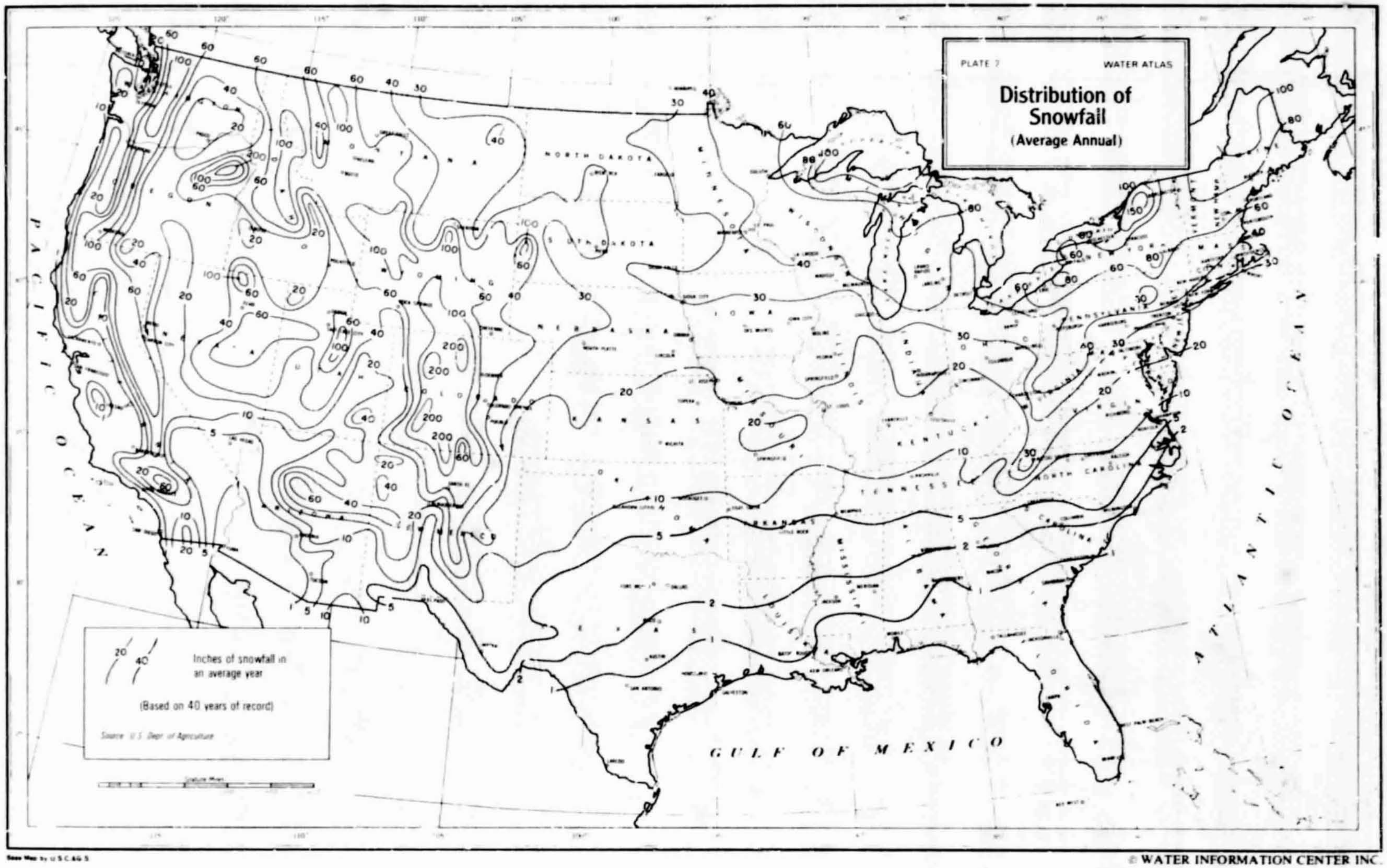

Figure G-18. Average Annual Snowfall (Source: Geraghty, et al, 1973)

G.4 METEOROLOGICAL AND HYDROGEOLOGICAL CONDITIONS: WIND

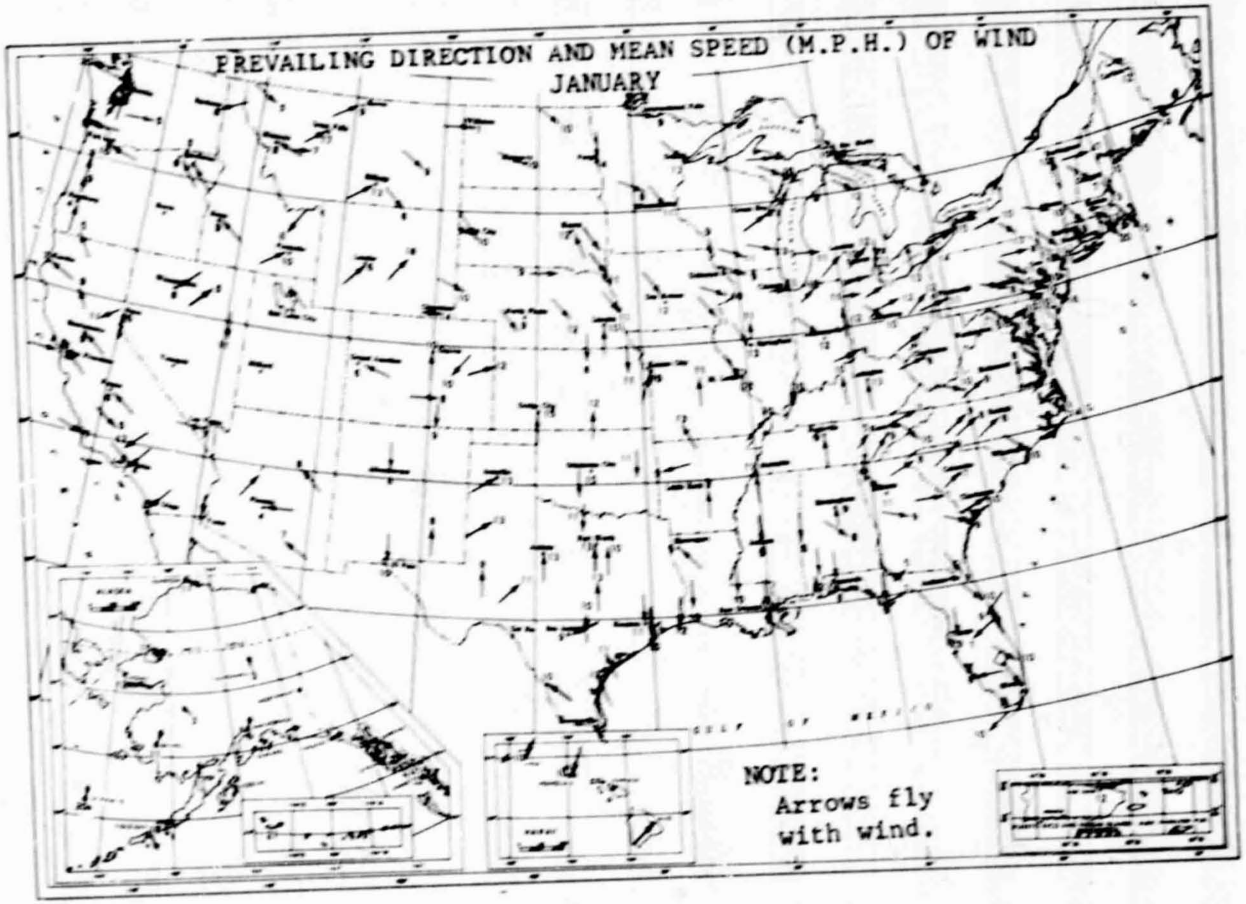

Figure G-19. Prevailing Direction and Mean Speed (mph) of Wind, January
(Source: U.S. Dept. of Commerce, 1979)

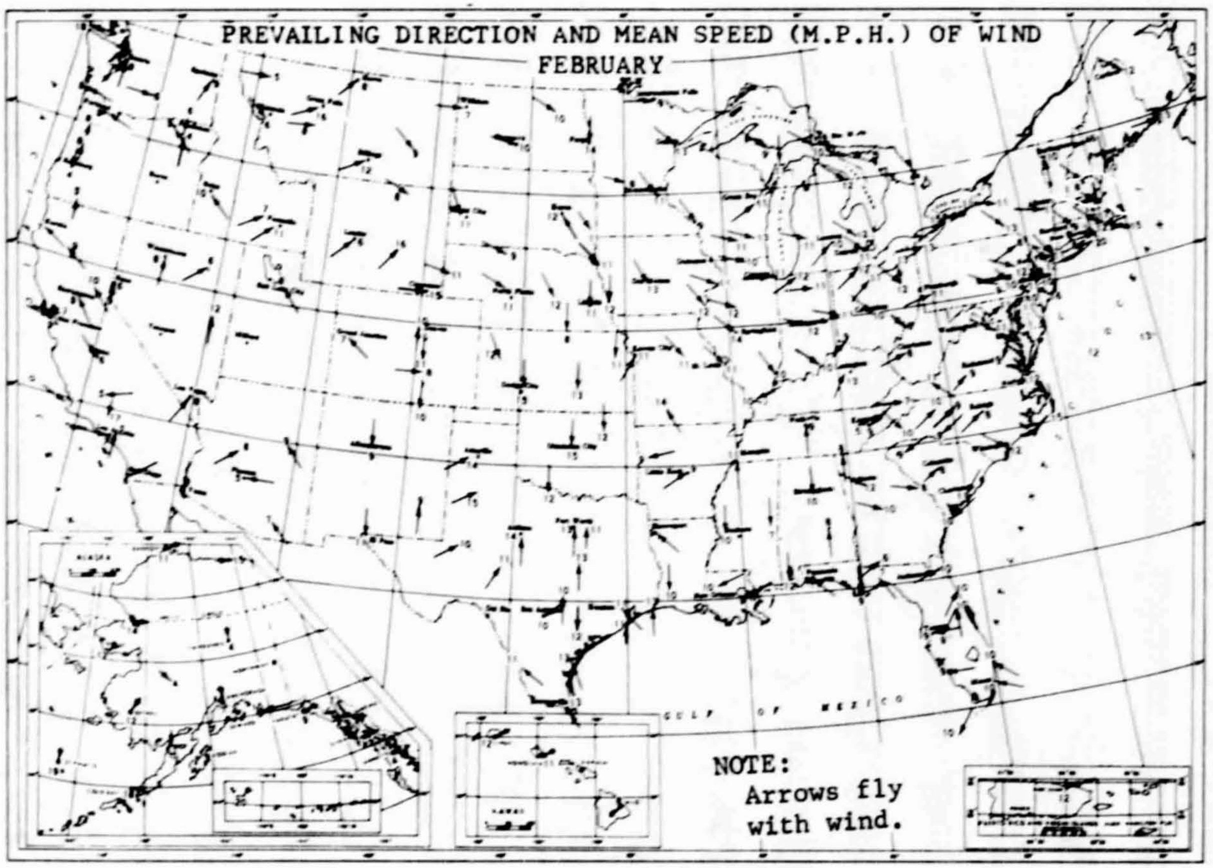

Figure G-20. Prevailing Direction and Mean Speed (mph) of Wind, February
(Source: U.S. Dept. of Commerce, 1979)

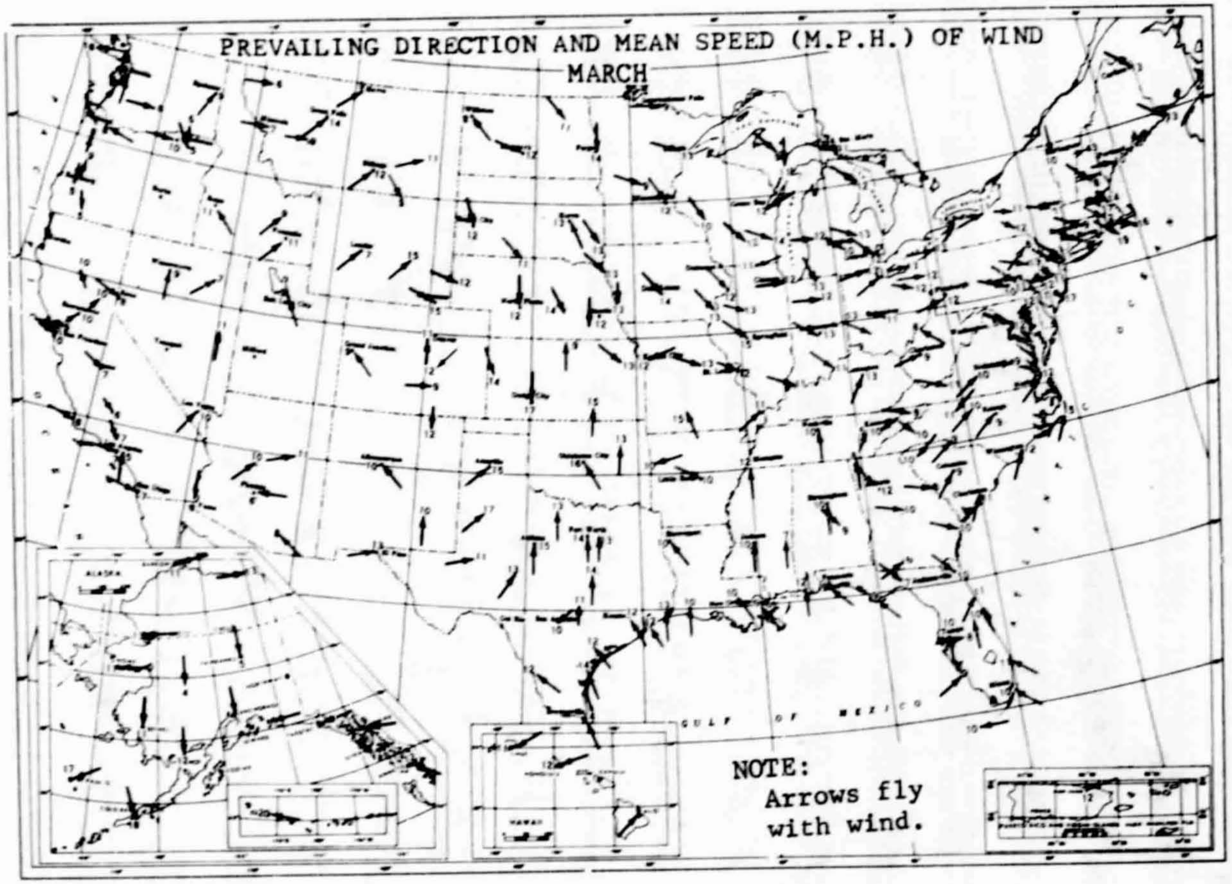

Figure G-21. Prevailing Direction and Mean Speed (mph) of Wind, March
(Source: U.S. Dept. of Commerce, 1979)

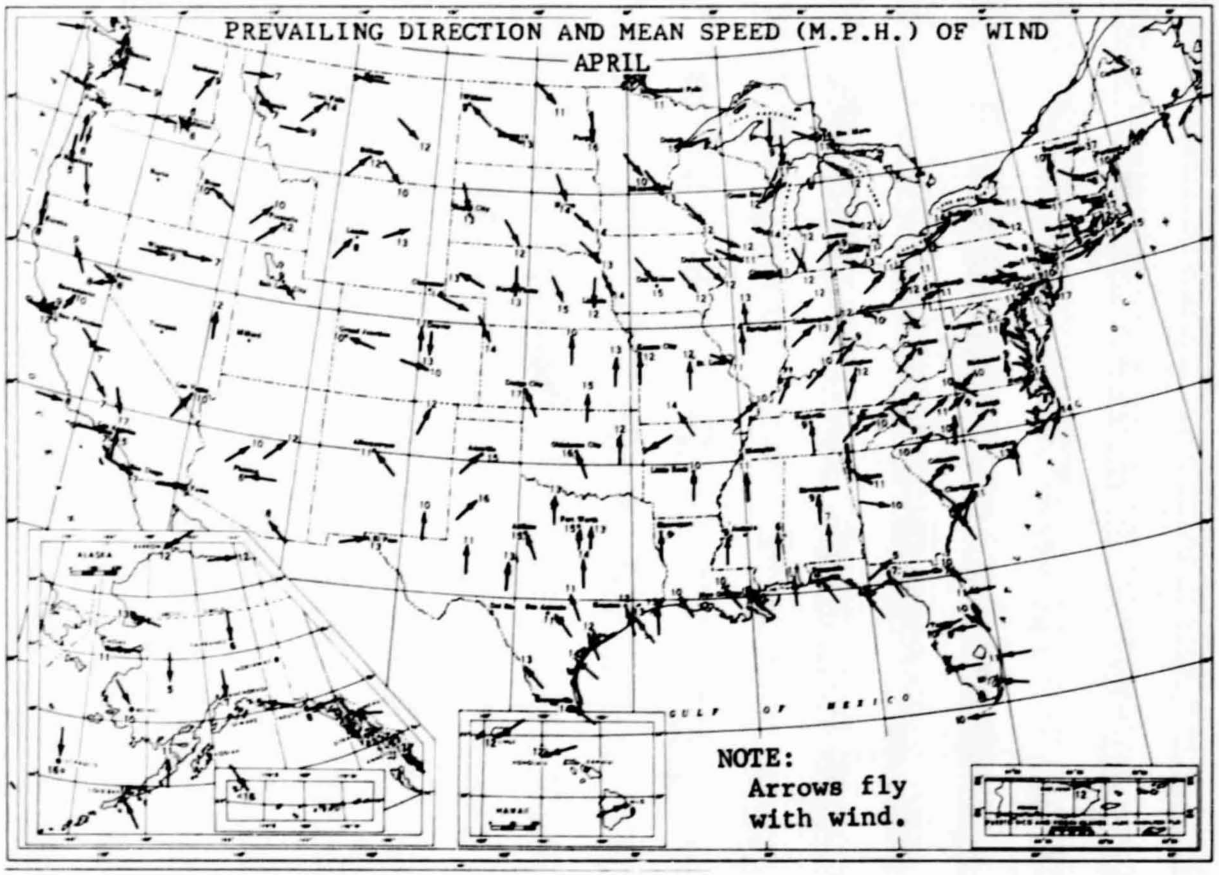

Figure G-22. Prevailing Direction and Mean Speed (mph) of Wind, April
(Source: U.S. Dept. of Commerce, 1979)

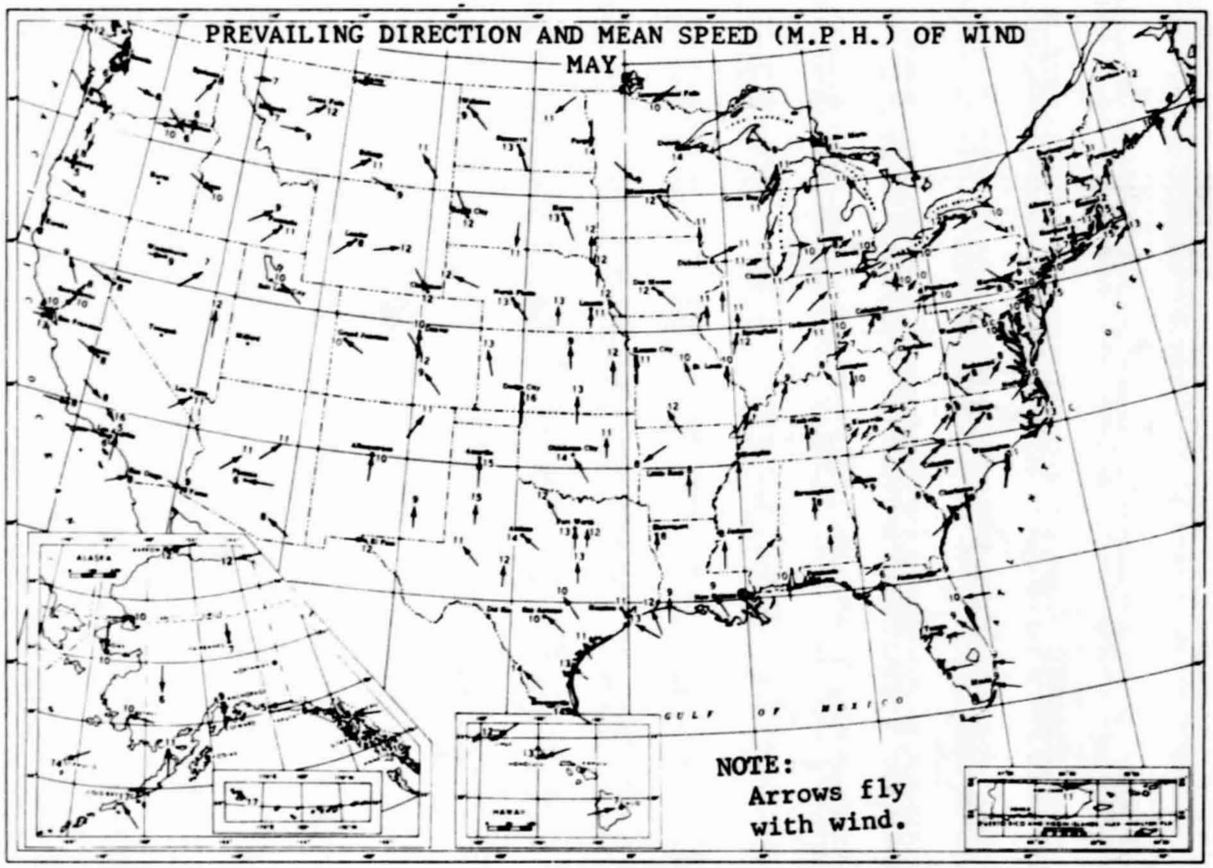

Figure G-23. Prevailing Direction and Mean Speed (mph) of Wind, May
(Source: U.S. Dept. of Commerce, 1979)

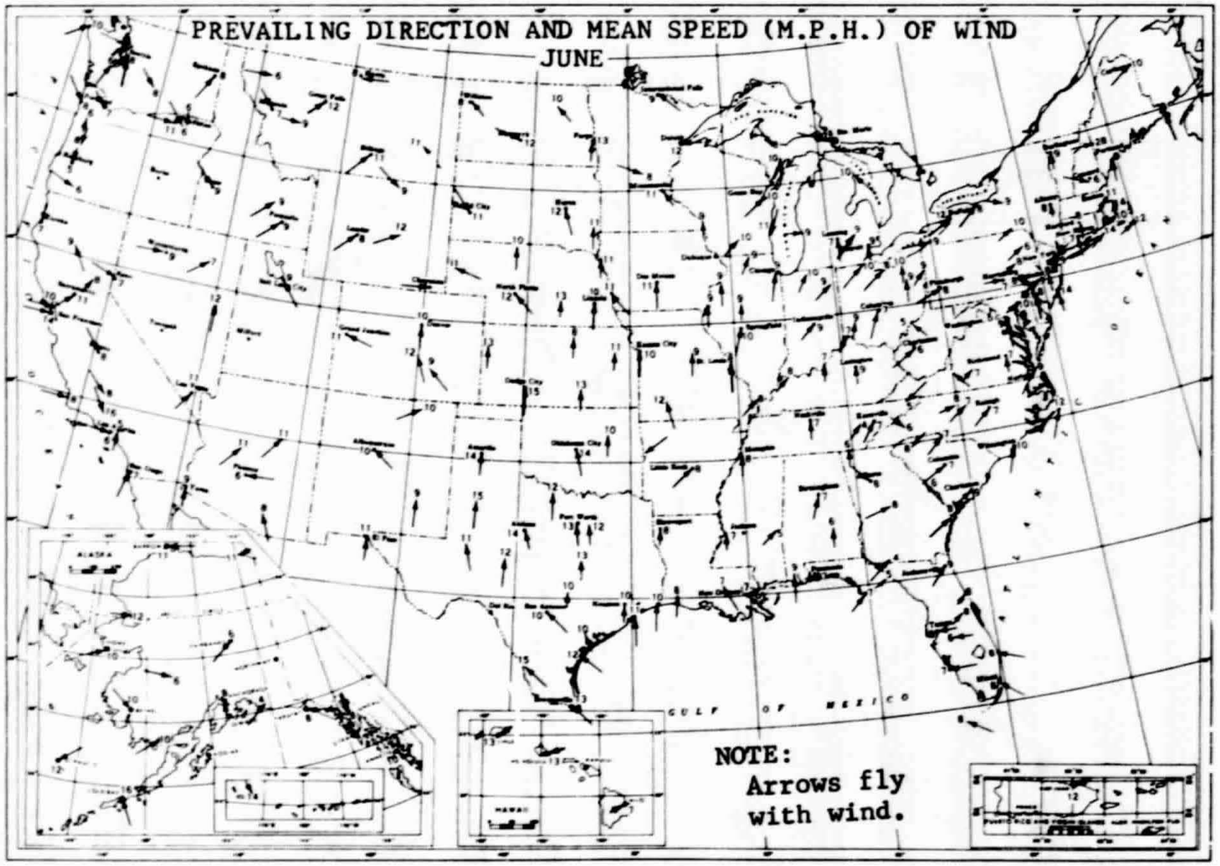

Figure G-24. Prevailing Direction and Mean Speed (mph) of Wind, June
(Source: U.S. Dept. of Commerce, 1979)

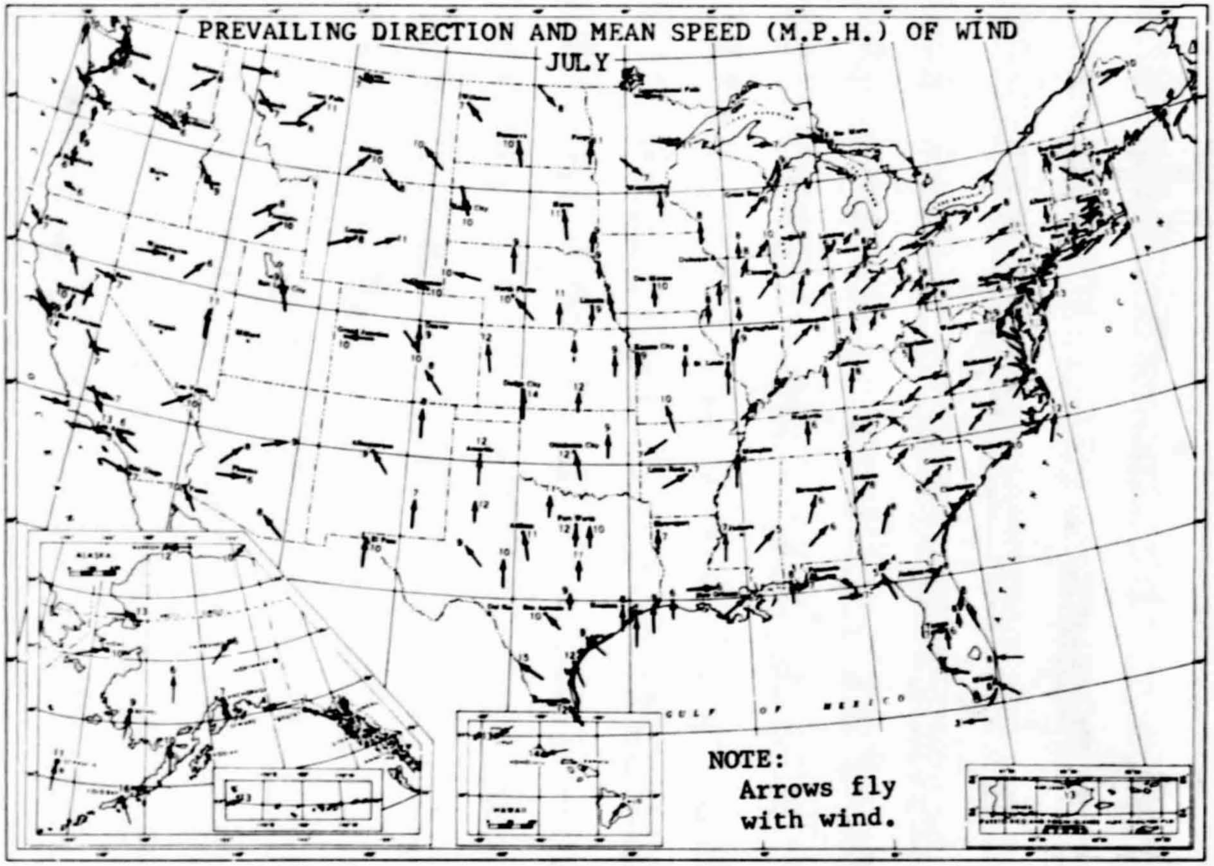

Figure G-25. Prevailing Direction and Mean Speed (mph) of Wind, July
(Source: U.S. Dept. of Commerce, 1979)

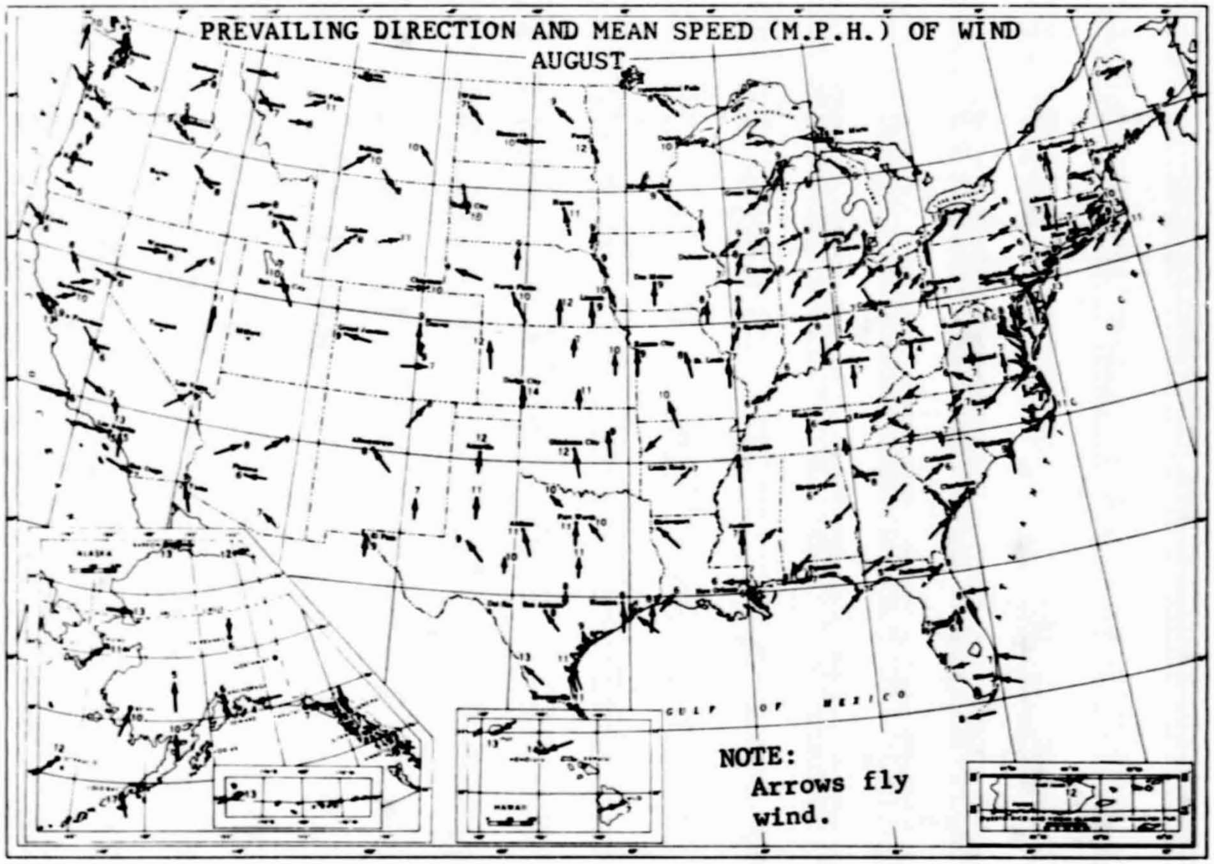

Figure G-26. Prevailing Direction and Mean Speed (mph) of Wind, August
(Source: U.S. Dept. of Commerce, 1979)

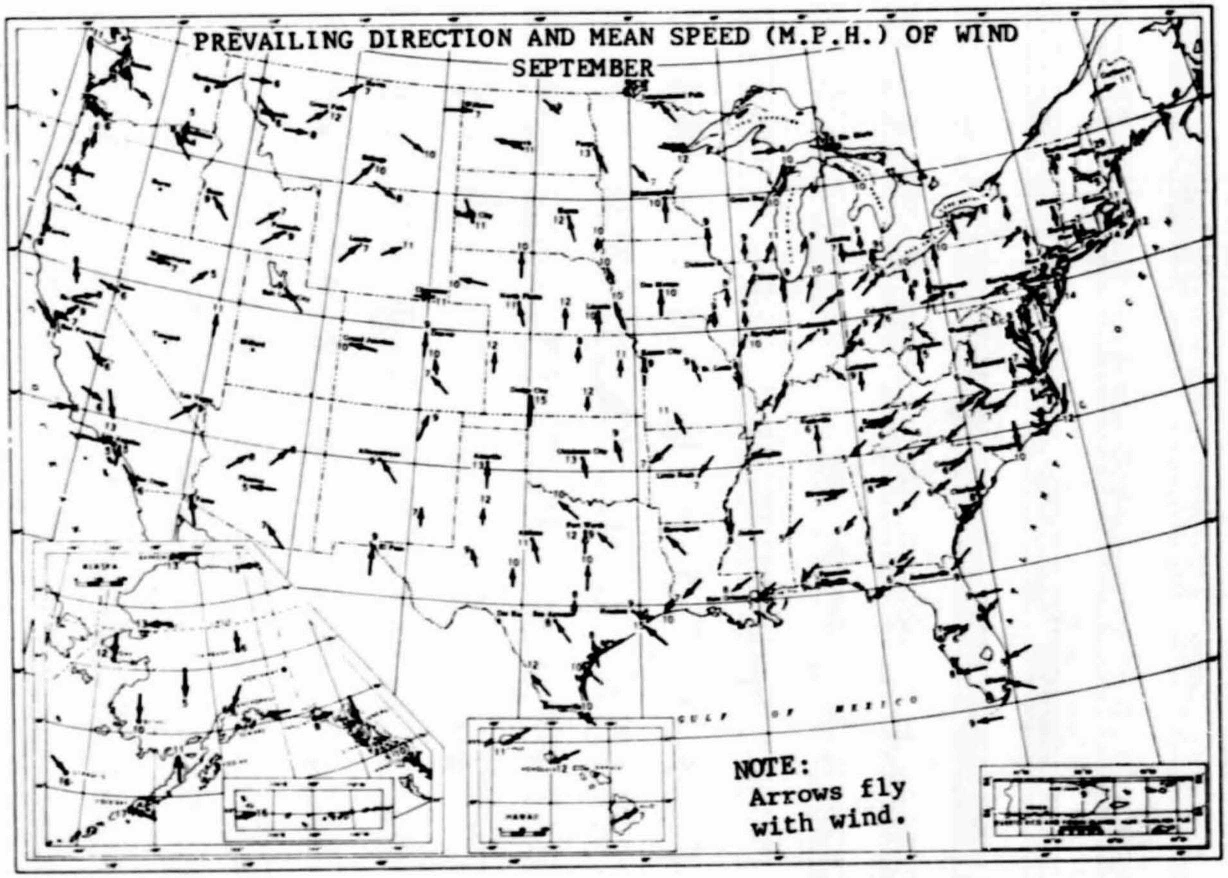

Figure G-27. Prevailing Direction and Mean Speed (mph) of Wind, September
(Source: U.S. Dept. of Commerce, 1979)

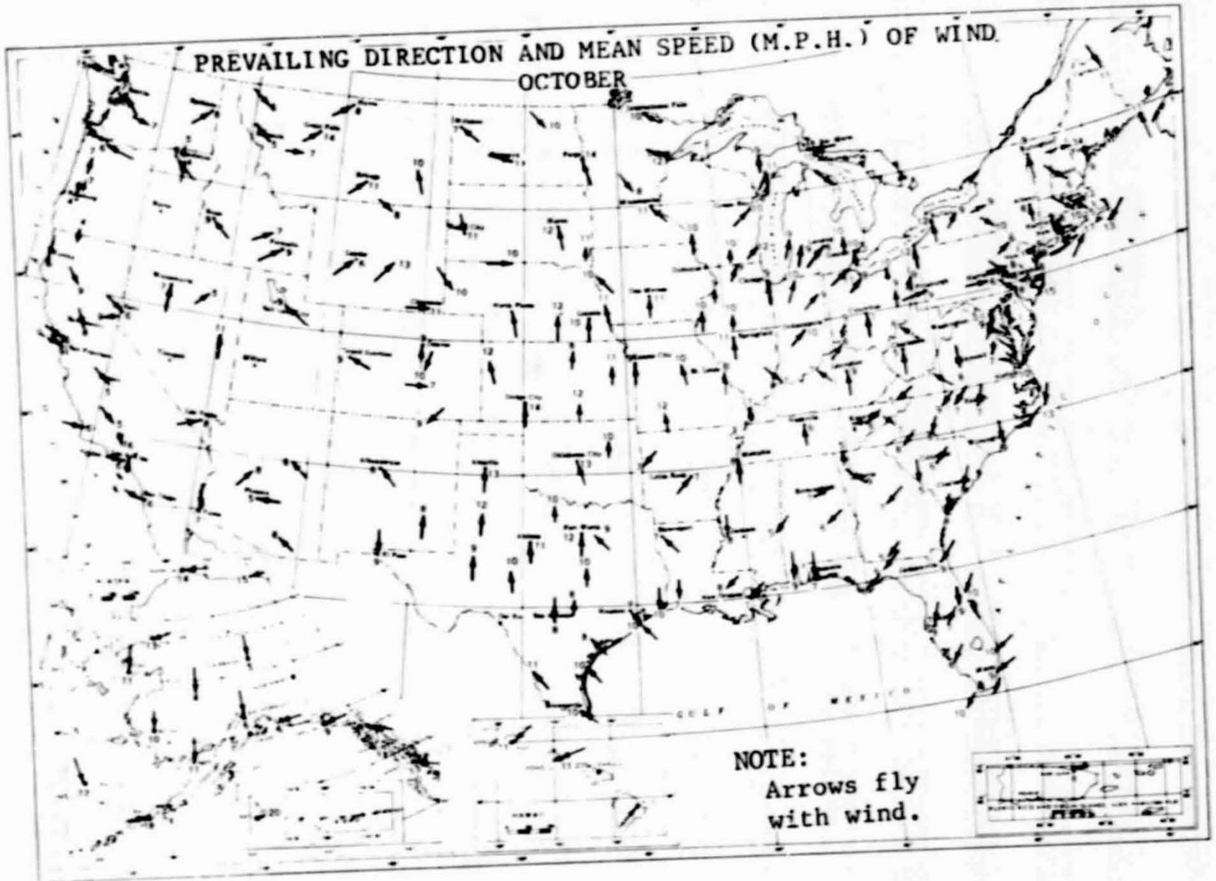

Figure G-28. Prevailing Direction and Mean Speed (mph) of Wind, October
(Source: U.S. Dept. of Commerce, 1979)

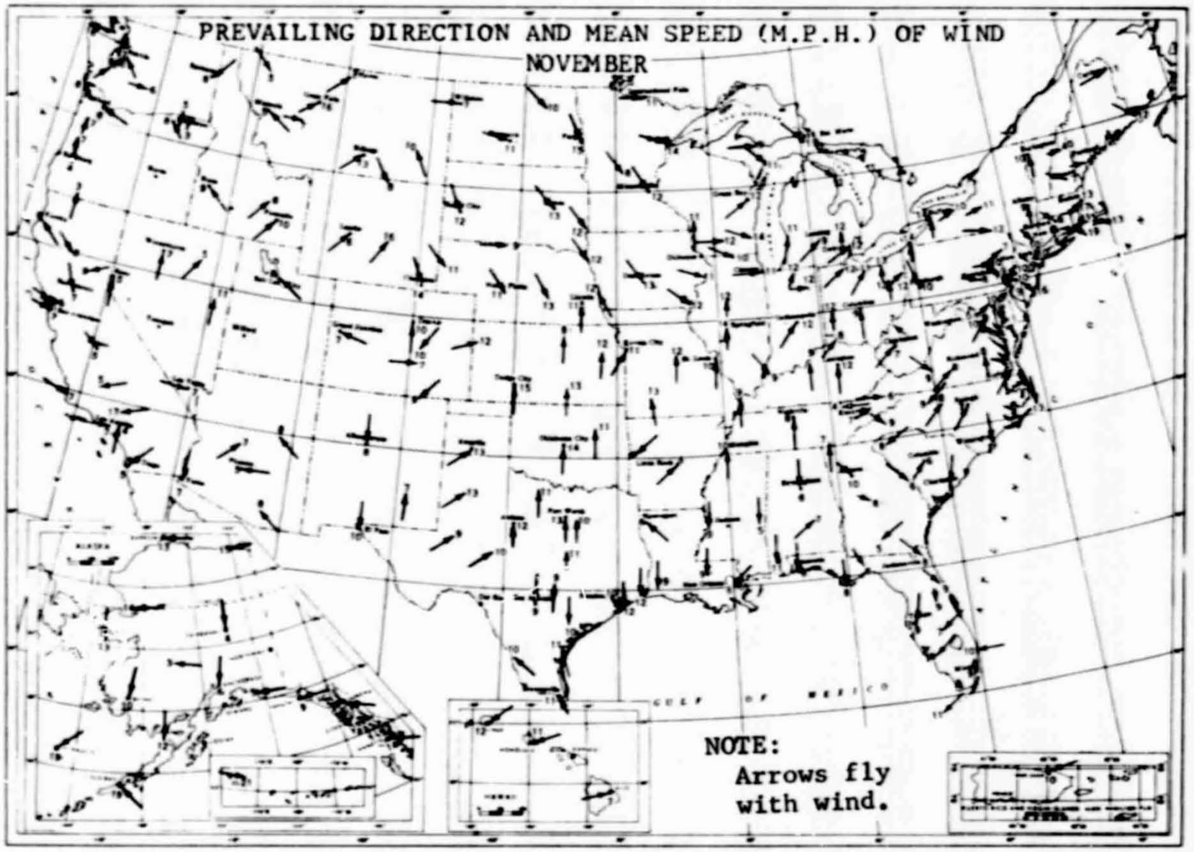

Figure G-29. Prevailing Direction and Mean Speed (mph) of Wind, November
(Source: U.S. Dept. of Commerce, 1979)

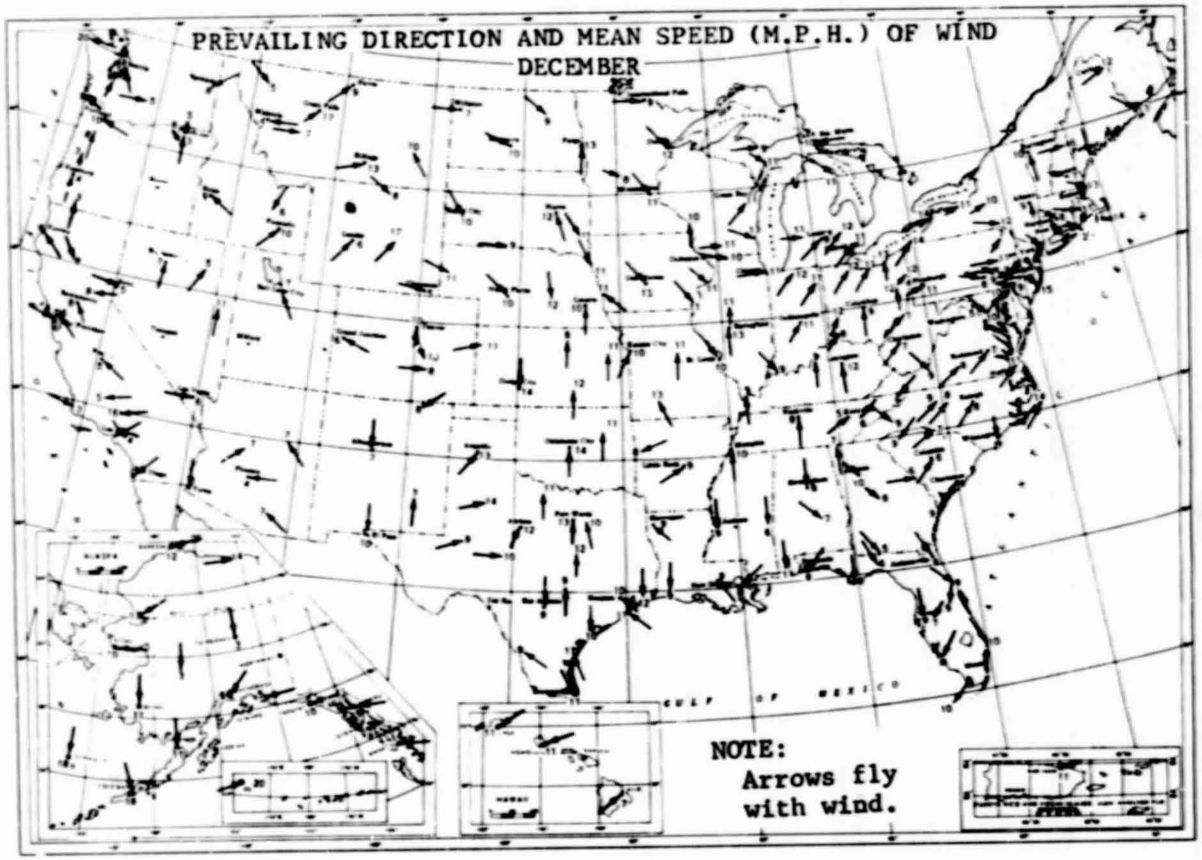

Figure G-30. Prevailing Direction and Mean Speed (mph) of Wind, December
(Source: U.S. Dept. of Commerce, 1979)

G.5 METEOROLOGICAL AND HYDROGEOLOGICAL CONDITIONS: SEISMIC ACTIVITY

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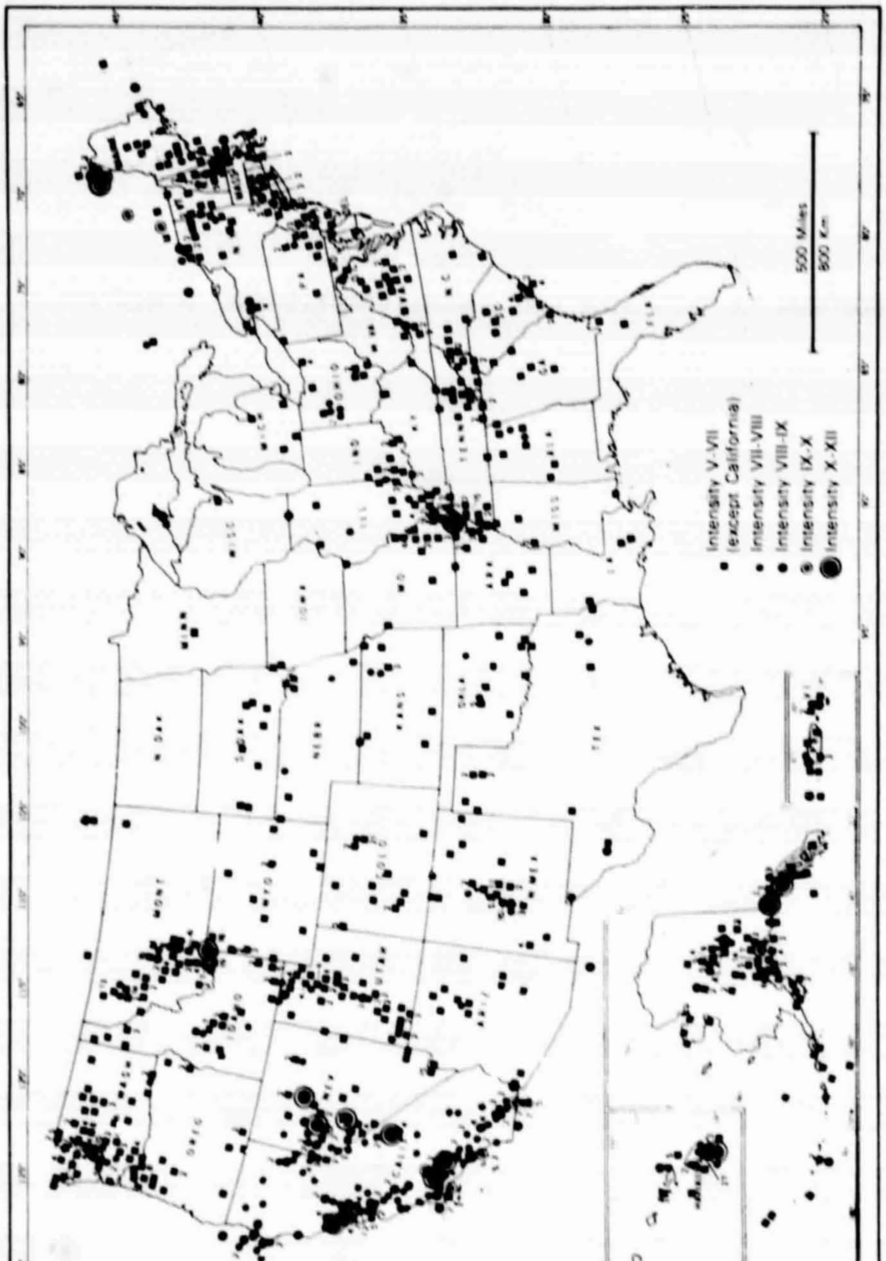

Figure G-31. Sesimic Activity in the United States

G.6 METEOROLOGICAL AND HYDROGEOLOGICAL CONDITIONS: HUMIDITY

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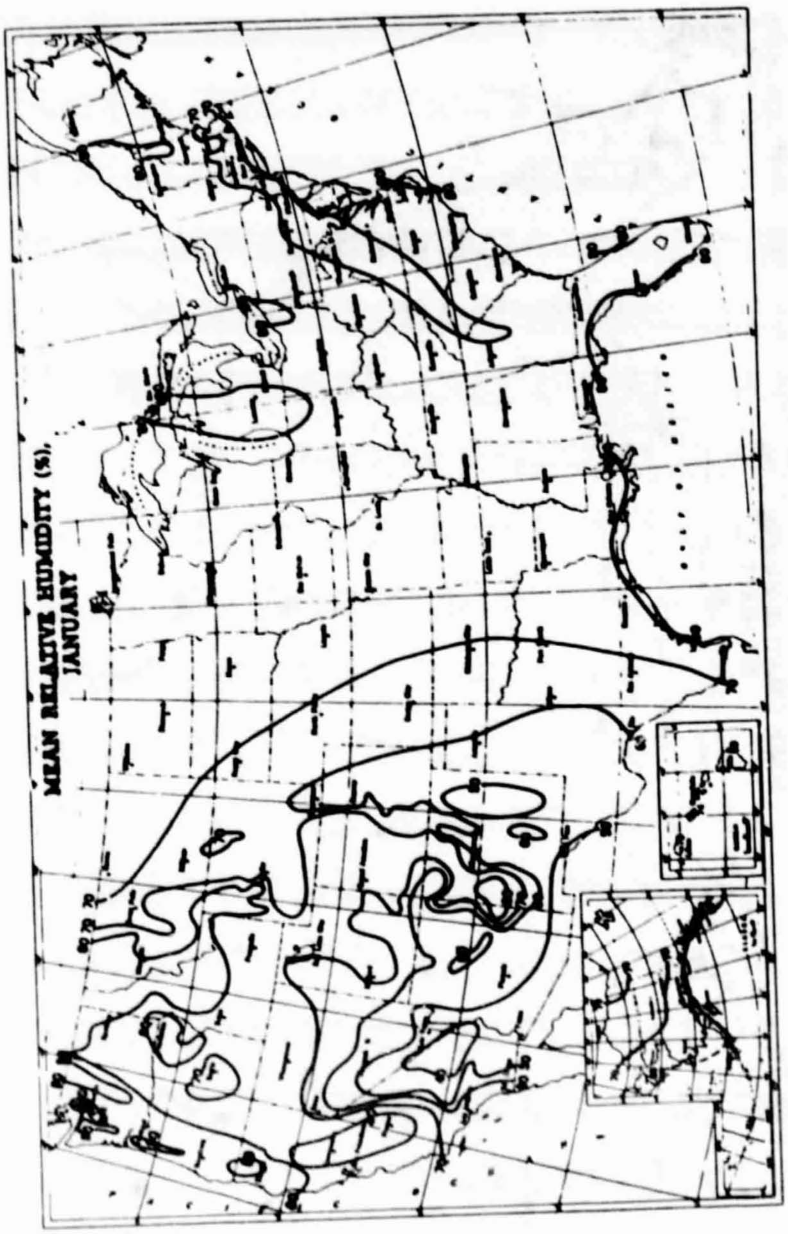


Figure G-32. Mean Relative Humidity (%), January (Source: U.S. Dept. of Commerce, 1979)

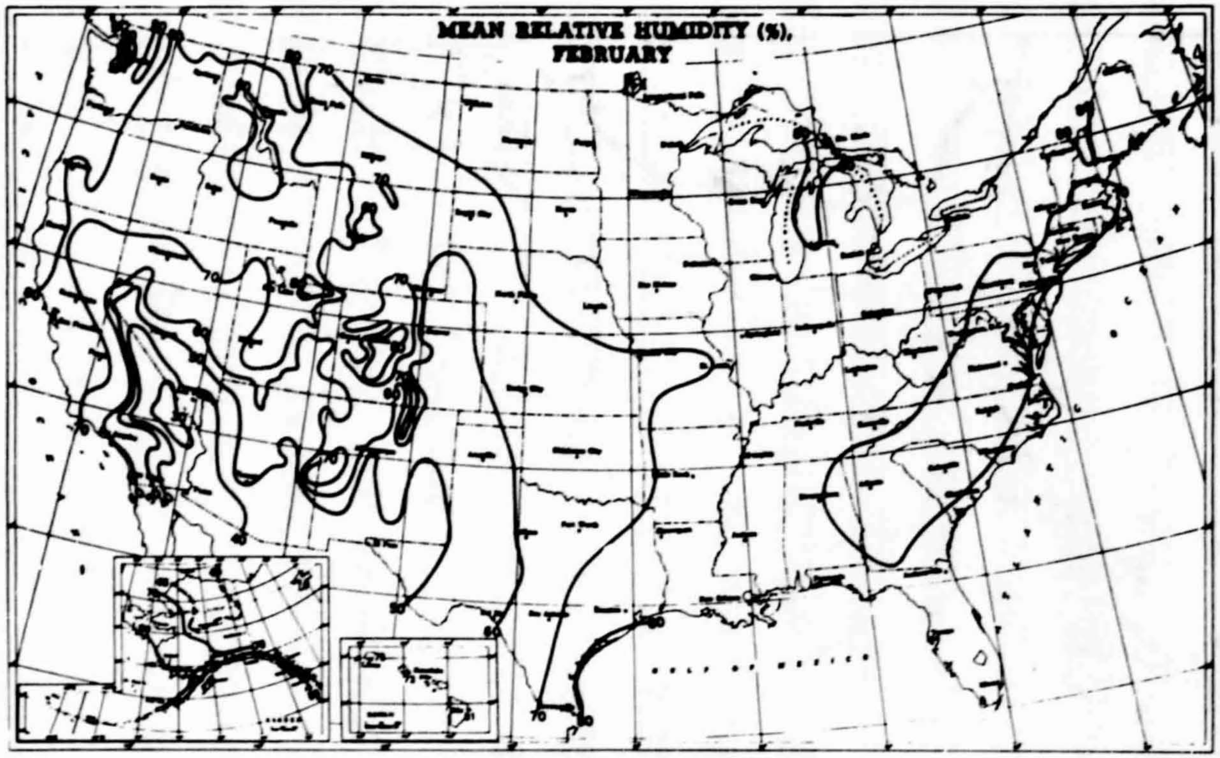


Figure G-33. Mean Relative Humidity (%), February (Source: U.S. Dept. of Commerce, 1979)

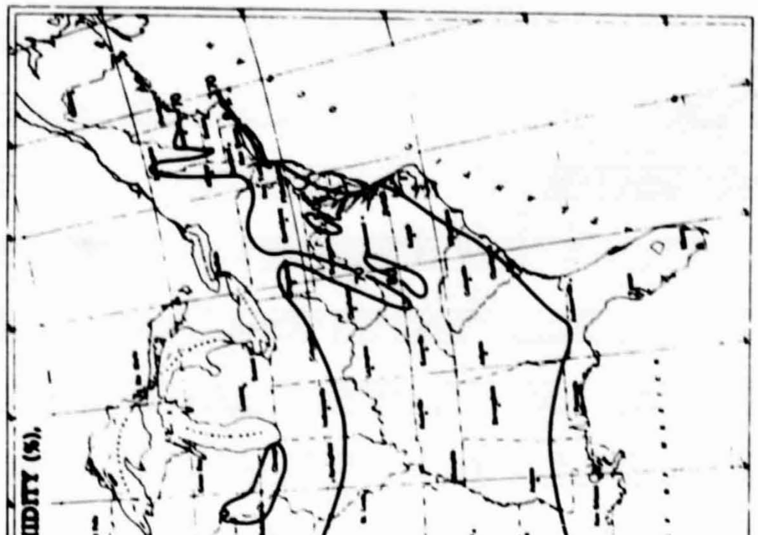


Figure G-34. Mean Relative Humidity (%), March (Source: U.S. Dept. of Commerce, 1979)

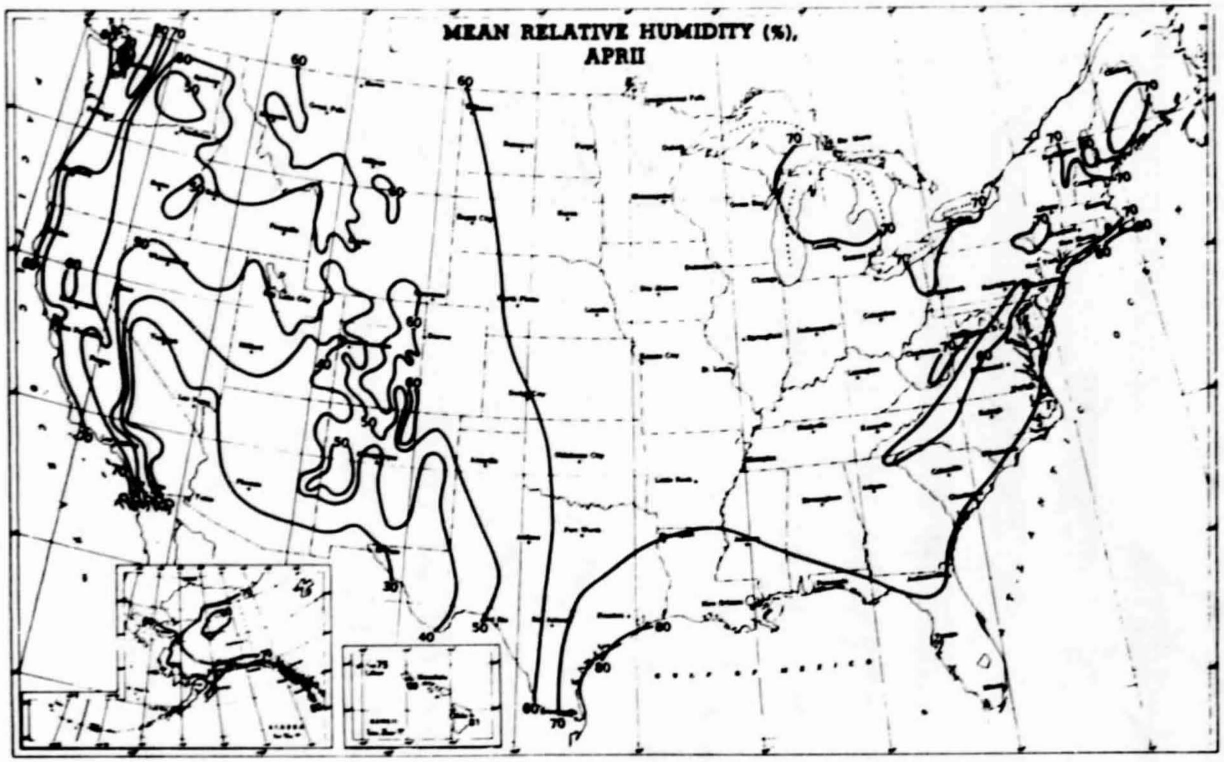


Figure G-35. Mean Relative Humidity (%), April (Source: U.S. Dept. of Commerce, 1979)

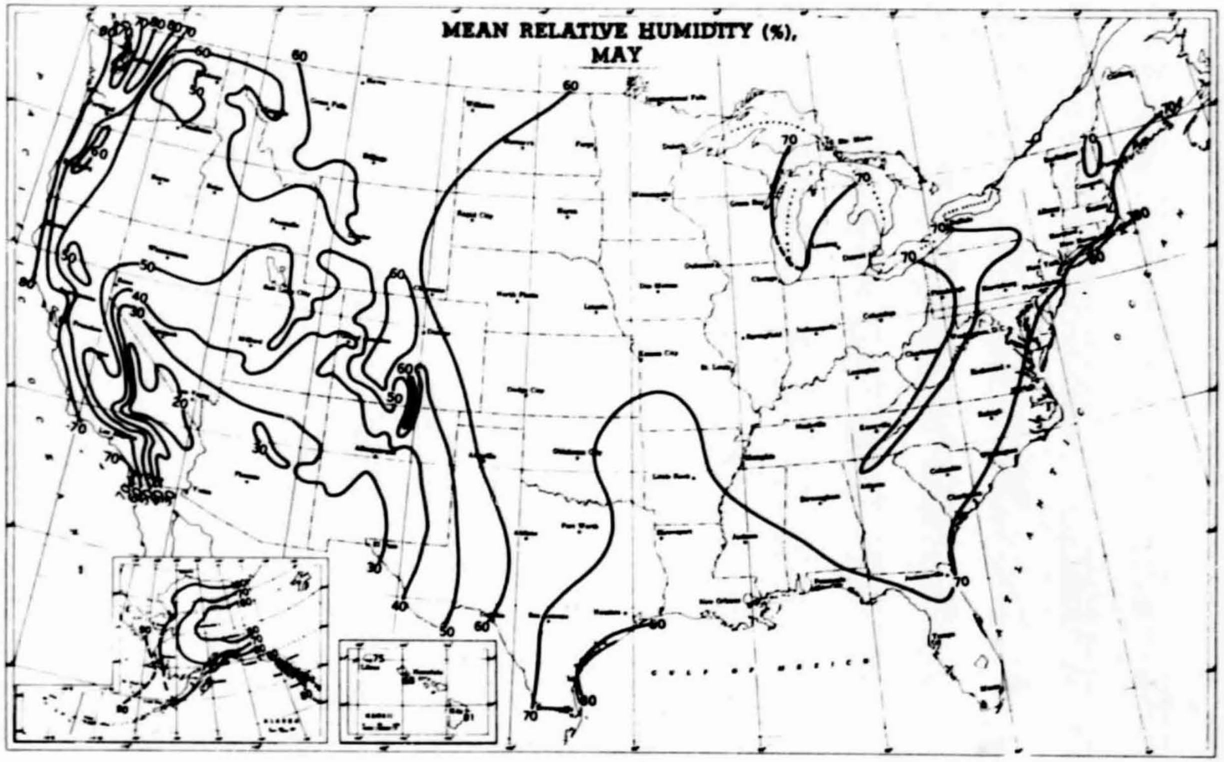


Figure G-36. Mean Relative Humdity (%), May (Source: U.S. Dept. of Commerce, 1979)

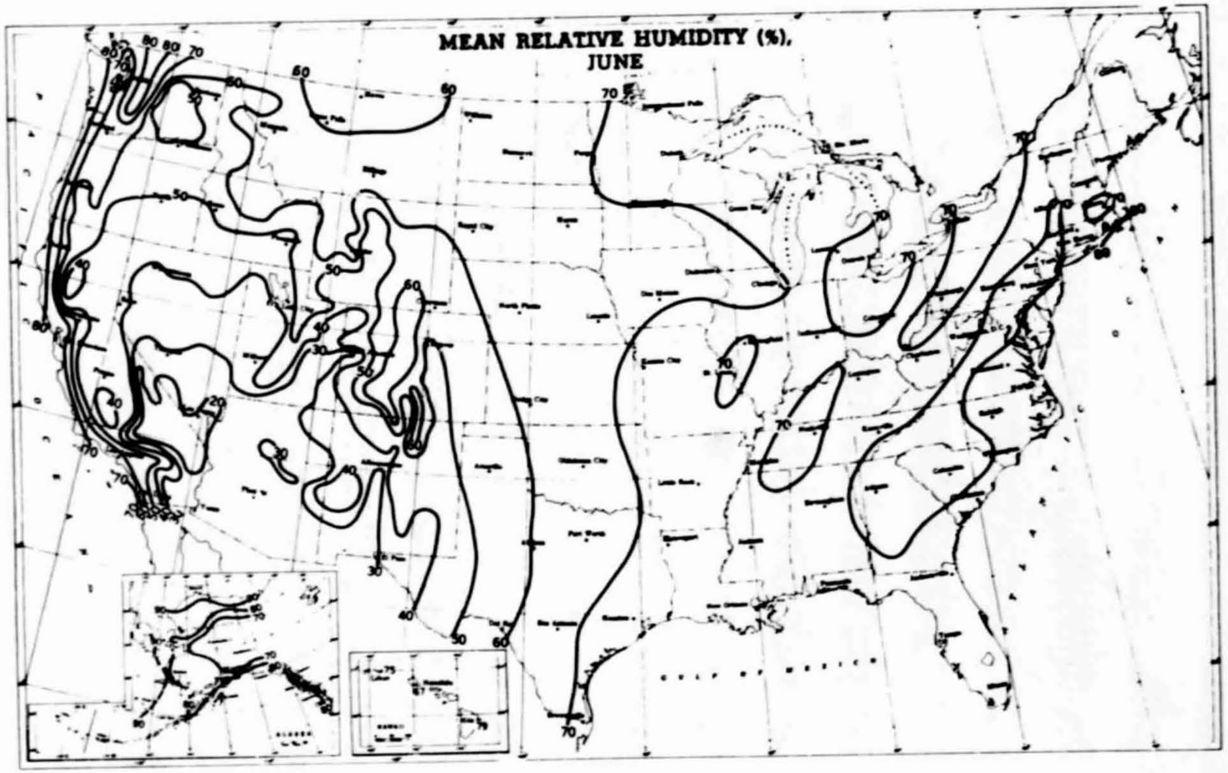


Figure G-37. Mean Relative Humidity (%), June (Source: U.S. Dept. of Commerce, 1979)

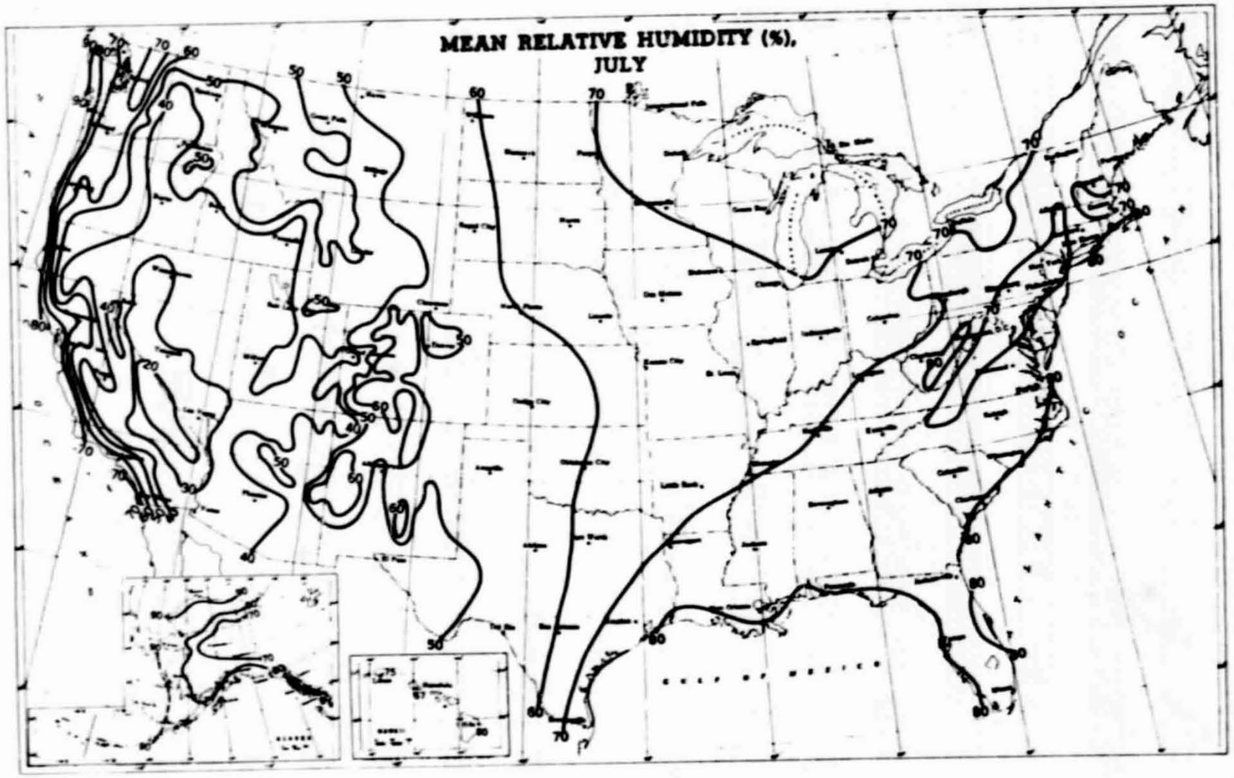


Figure G-38. Mean Relative Humdity (%), July (Source: U.S. Dept of Commerce, 1979)

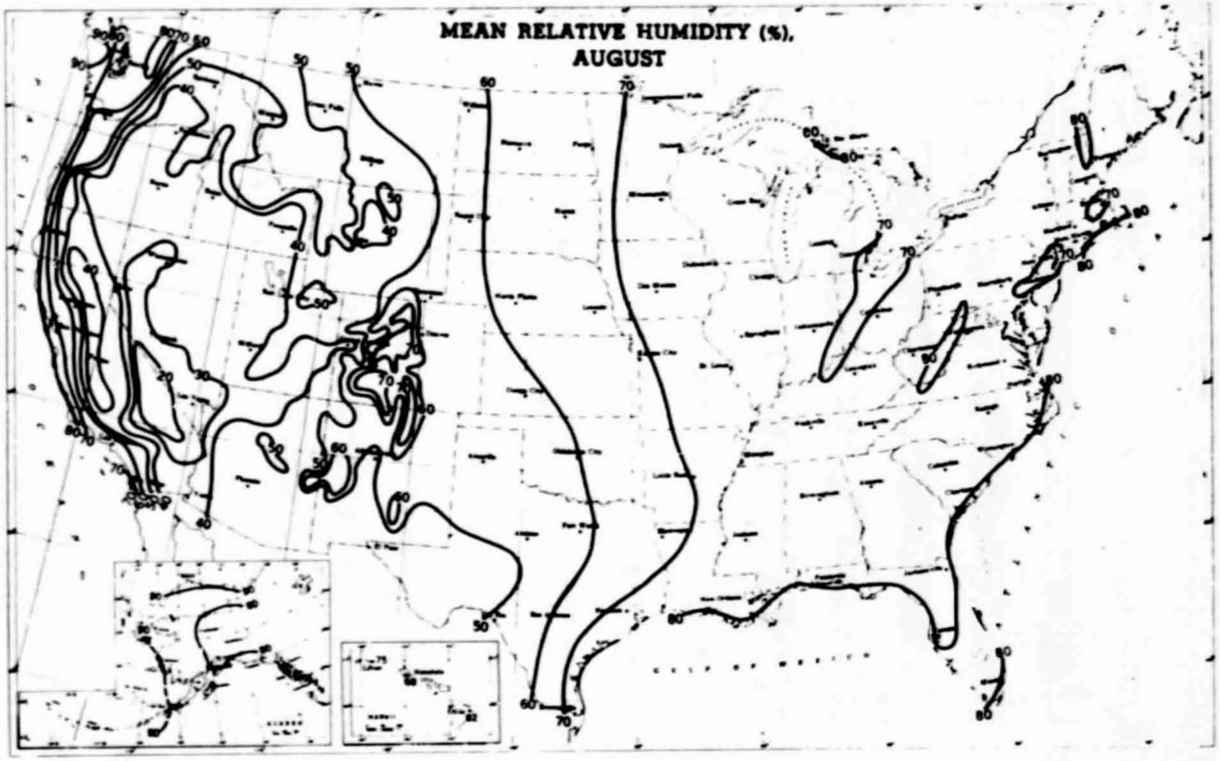


Figure G-39. Mean Relative Humidity (%), August (Source: U.S. Dept. of Commerce, 1979)

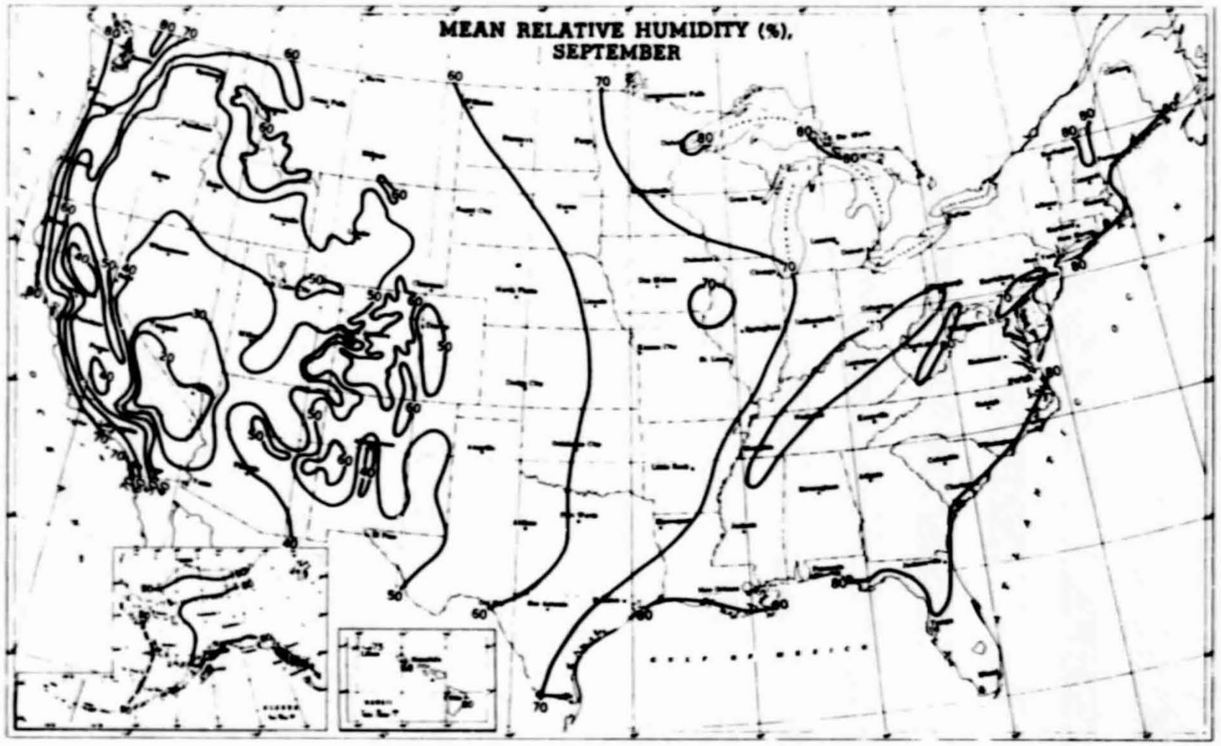


Figure G-40. Mean Relative Humidity (%), September (Source: U.S. Dept. of Commerce, 1979)

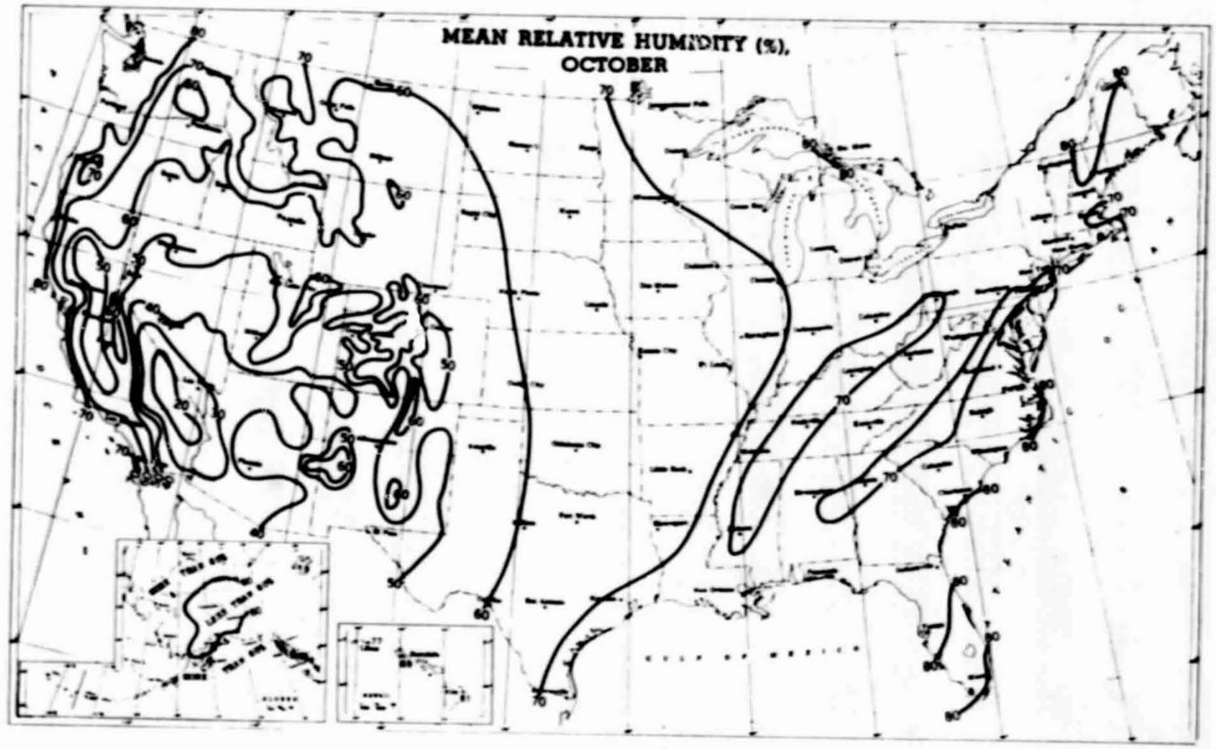


Figure G-41. Mean Relative Humidity (%), October (Source: U.S. Dept. of Commerce, 1979)

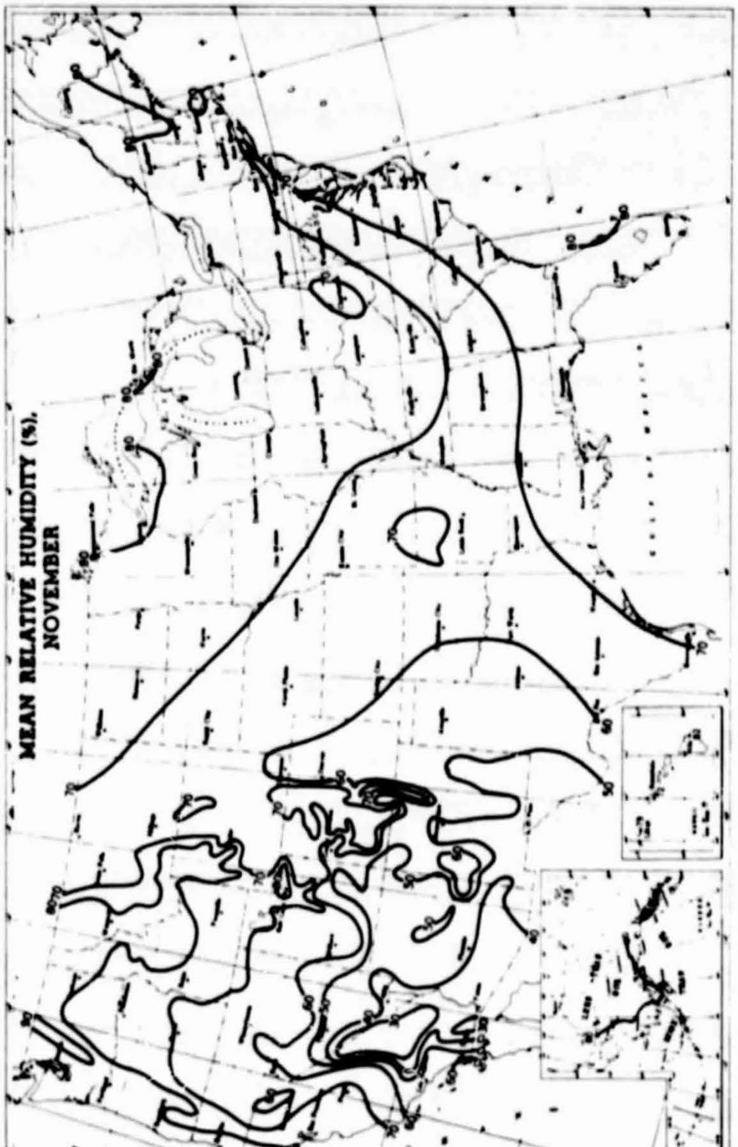


Figure G-42. Mean Relative Humdity (%), November (Source: U.S. Dept. of Commerce, 1979)

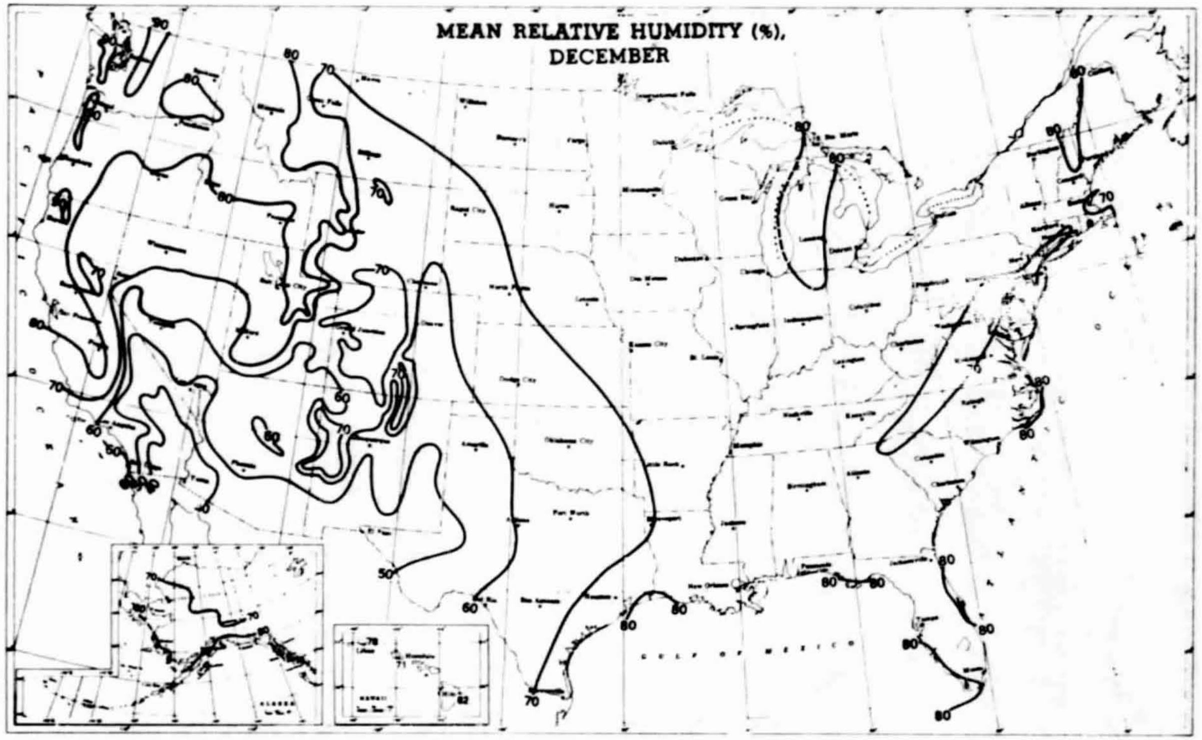


Figure G-43. Mean Relative Humidity (%), December (Source: U.S. Dept. of Commerce, 1979)

APPENDIX H

DETAILED DESCRIPTION OF THE JPL SOLAR POND PERFORMANCE MODEL

APPENDIX H

DETAILED DESCRIPTION OF THE JPL SOLAR POND PERFORMANCE MODEL

H.1 MATHEMATICAL FORMULATION

H.1.1 DIFFERENTIAL EQUATION AND BOUNDARY CONDITIONS

The temperature distribution, T(t,z) is given by

$$(\rho C_p)_f(\partial T/\partial t) = k_f(\partial^2 T/\partial z^2) + \dot{Q}(t,z) \quad (1)$$

in the middle non-convecting zone (MNZ) and by

$$(\rho C_p)_g(\partial T/\partial t) = k_g(\partial^2 T/\partial z^2) \quad (2)$$

in the ground (GRD), where

- T = temperature (^oC)
- ρ = fluid or ground density (kg/m^3)
- C_p = fluid or ground specific heat ($W - s/kg - {}^oC$)
- k = fluid or ground thermal conductivity ($W/m - {}^oC$)
- $\dot{Q}$ = volumetric insolation absorption rate (W/m^3)
- t = time (s) from January 1, 12:00 A.M.
- z = depth below pond surface (m)

and the subscripts f and g denote fluid and ground, respectively.

Equations (1) and (2) may be solved by the method of finite differences. The JPL code is derived from an explicit formulation with time and depth increments of Δt = 21,600 s = 0.25 days and Δz = 0.1 m, respectively. The thermal circuit is shown in Figure H-1.

The temperature of the upper convecting zone(UCZ)is specified by a curve fit to monthly-averaged ambient temperature values. Diurnal fluctuations are not considered.

$$T_{UCZ} = A' + B' \sin [2\pi(t - C')/(365 \times 86,400)] \ {}^oC \quad (3)$$

THERMAL CIRCUIT

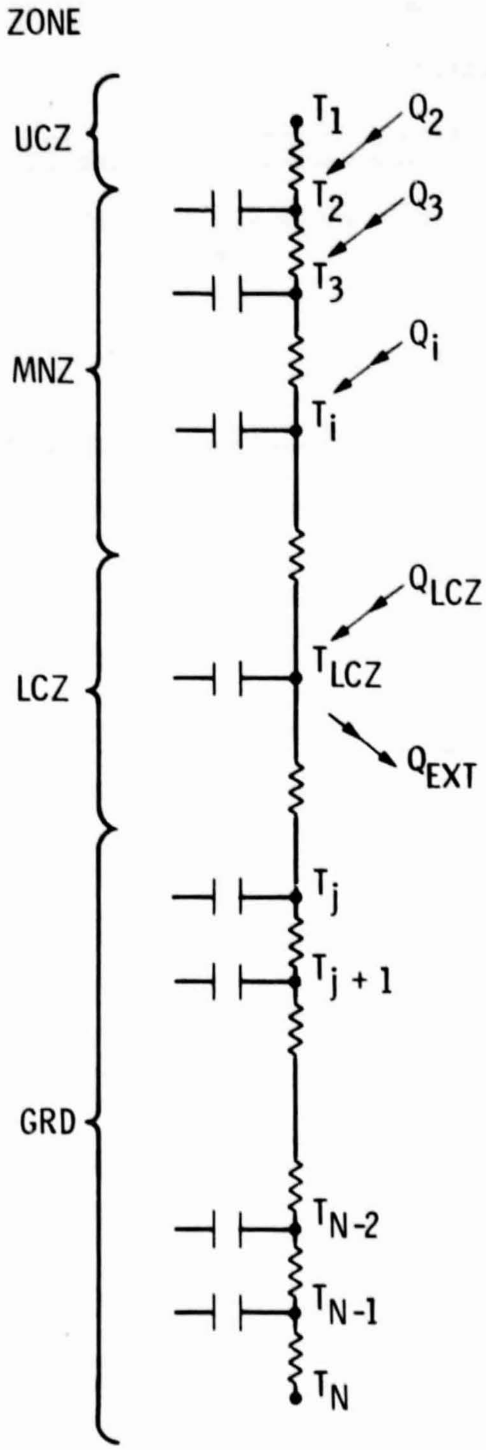


Figure H-1. Thermal Circuit

The initial condition sets the water temperature at the ambient temperature given by Equation 3 and the ground temperature (to a depth of 10 m) at the annual-average temperature.

H.1.2 Energy Extraction

In order to approach constant daily output from the power plant, the solar pond must store summer energy for release in the winter. This will necessitate a storage-zone temperature that rises during the summer months and falls during the winter months. Ormat has found that the temperature will vary sinusoidally, peaking in the fall and dropping to a minimum in the spring.

$$T'_{LCZ} = A'' + B'' \sin [2\pi(t - C'')/(365 \times 86{,}400)] \ ^{o}C \qquad (4)$$

Several operational options have been programmed for control of the model. In one option the lower-zone temperature is contained on the high side by Equation 4. Thus the storage temperature is given by

$$T_{LCZ} = \min [T'_{LCZ}, T''_{LCZ}] \ ^{o}C \qquad (5)$$

T''_{LCZ} is the temperature the (LCZ) for the case of no heat extraction and is given by Equation 1.

The rate of heat extraction for time step n is given by

$$\dot{Q}_{ext}(n) = \max \left\{ 0., \ (\rho C_p)_f A \ D_{LCZ} \times [T''_{LCZ}(n) - T'_{LCZ}(n)]/\Delta t \right\} \quad W \qquad (6)$$

where A is the solar pond area (m^2) and D_{LCZ} is the thickness of the LCZ (m).

A second control option accepts monthly energy delivery requirements with a minimum limit on storage temperature. The energy delivery schedule is satisfied so long as the LCZ temperature remains above the specified minimum. Below the specified minimum, no energy is extracted.

H.1.3 Insolation Source Function

The rate at which insolation reaches a depth z is given by

$$\dot{I} = \gamma(t) \ P(\ell) \ \tau_n(t) \qquad (7)$$

where P [illegible] a polynomial fit to the data presented in Figure H-2. The path length is given by

$$\ell = z \ / \ \cos r \qquad (8)$$

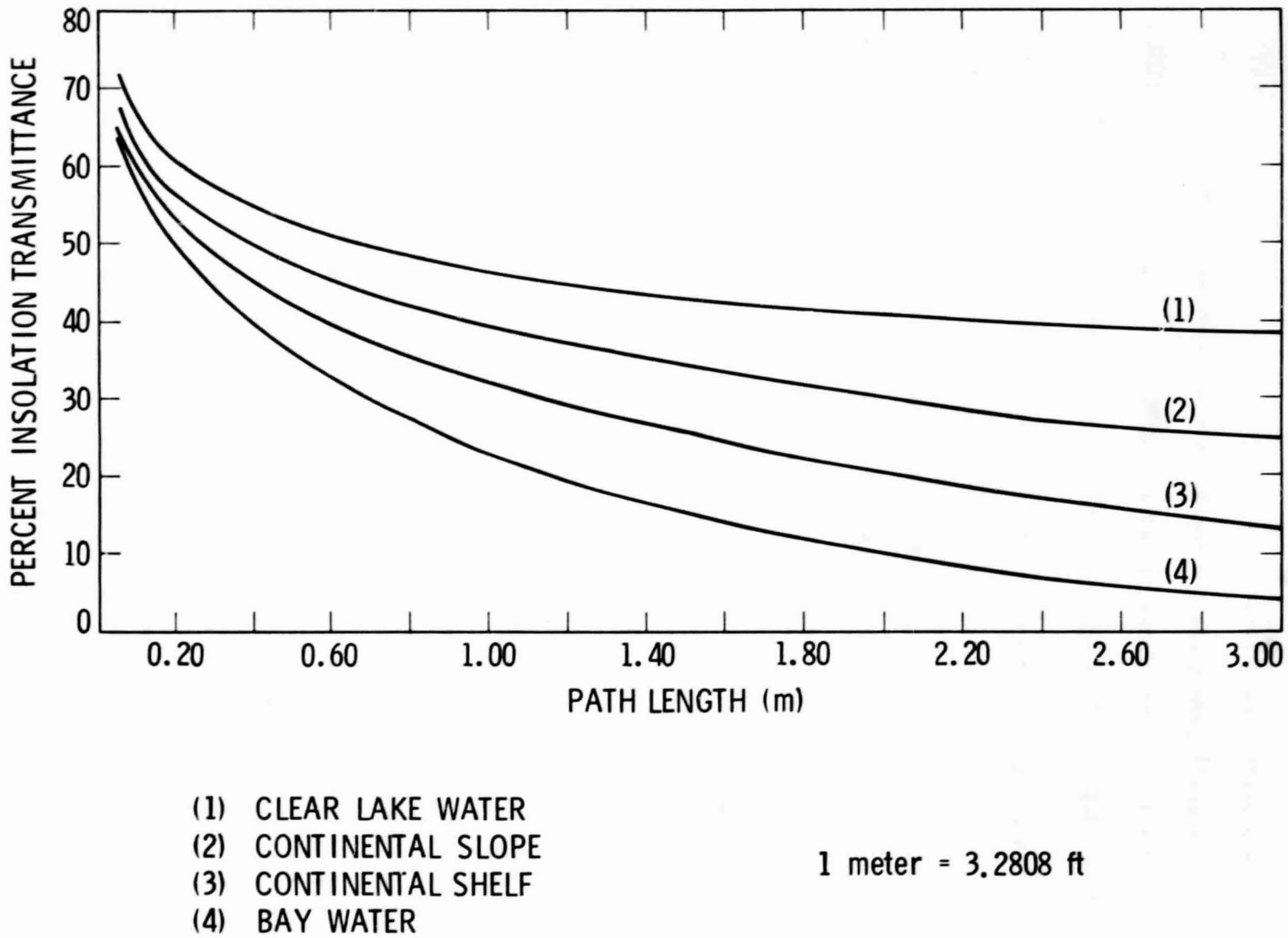


Figure H-2. Transmittance Data for Four Water Types (Source: Ormat Turbines, Ltd. 1981)

where r is the angle of refraction and is given by

$$r = \sin^{-1} (\sin i \; / \; N) \tag{9}$$

$$i = \cos^{-1} [\sin \delta \sin L - \cos \delta \cos L \cos (2\pi t/86{,}400)], \text{ and}$$

$$N = 1.33 \text{ is the index of refraction} \tag{10}$$

where i is the angle of incidence and L is the site latitude. The solar declination δ is given by

$$\delta = 0.409 \sin \left\{ 2\pi[t - (79 \times 86{,}400)]/(365 \times 86{,}400) \right\} \tag{11}$$

The function $\gamma(t)$ is the rate of insolation just penetrating the pond surface. Eighty-five percent of insolation is assumed to be direct and the remainder hemispherically distributed diffuse radiation.

$$\gamma(t) = [0.85\,\theta(t) + 0.14]\, \dot{I}'(t) \tag{12}$$

where 7% of the diffuse radiation is reflected. $\theta(t)$ is the fractional penetration of direct insolation and is computed from the Fresnel equations:

$$\theta(t) = 1 - 0.5\, [(\sin^2(i - r)/\sin^2(i + r) + \tan^2(i - r)/\tan^2(i + r)] \tag{13}$$

The fractional penetration of insolation through the floating wave-suppression network is

$$\tau_n(t) = 0.71 + 0.29 \left(0.88 + 0.06 \sin \left\{ 2\pi[t - (79 \times 86{,}400)]/ (365 \times 86{,}400) \right\} \right) \tag{14}$$

The insolation incident on the pond surface, I'(t), is assumed to vary diurnally as

$$\dot{I}'(t) = \begin{cases} \dot{I}''(t)\; 0.8^{\sec(i)} \cos(i) / \int 0.8^{\sec(i)} \cos(i)\, dt \quad \text{W/m}^2 \\ \qquad \text{between sunrise and sunset} \\ 0 \quad \text{W/m}^2 \\ \qquad \text{between sunset and sunrise} \end{cases} \tag{15}$$

where the limits on integration are sunrise and sunset on a given day. The JPL code assumes that insolation varies over the year according to

$$\dot{I}''(t) = a + b \sin \left\{ 2\pi[t - (73 \times 86{,}400)]/(365 \times 86{,}400) \right\} + c \cos \left\{ 2\pi[t - (73 \times 86{,}400)]/(365 \times 86{,}400) \right\} \quad \text{W/m}^2 \tag{16}$$

The constants a, b, and c are determined by a curve fit to monthly insolation values.

The JPL code also allows for a more exact treatment of transmittance as a function of wavelength and salt concentration. The dependence of transmittance on concentration appears to be important at least for the case of Salton Sea water and is discussed more completely elsewhere (Marsh, et al 1981).

The more precise treatment is accomplished by substituting $\tau_{\ell,T}$ for $P(\ell)$ in Equation 7, where

$$\tau_{\ell,T} = \int_{\lambda} f(\lambda') \quad \tau_{\ell}(\lambda') d\lambda' \ / \int_{\lambda} f(\lambda') d\lambda' \tag{17}$$

and $f(\lambda)$ is the continuous distribution function for insolation over all wavelengths, λ. The denominator in Eq. (17) is unity, by definition. It is assumed that the absorption of insolation is proportional to intensity (Lambert's Law),

$$d\,\tau(\lambda)/d\,\ell = -k(\lambda,C)\,\tau(\lambda) \tag{18}$$

where $k(\lambda,C)$ is an absorption coefficient. Integrating over path length,

$$\tau_{\ell}(\lambda) = \tau_{o}\ (\lambda)\ \exp\ [\ -\int_{\ell} k(\lambda,C)\ d\ell'\ ] \tag{19}$$

and the constant of integration, $\tau_o(\lambda)$, is set equal to unity for all wavelengths.

For computational purposes, discrete variables are substituted for continuous variables and the transmittance is averaged over the m wavelength bands as follows:

$$\tau_{\ell,T} = \sum_{i=1}^{m} f_i\ \tau_{\ell,i} / \sum_{i=1}^{m} f_i = \sum_{i=1}^{m} f_i\ \tau_{\ell,i} \tag{20}$$

and

$$\tau_{\ell,i} = \exp\ [\ -\int_{\ell} k_i(C)\ d\ell'\ ] \tag{21}$$

The required input is $k_i(C)$, which is derived from spectrophotometric data for a set of homogenous water samples.

$$k_i(C') = [\ln(- \tau_{\ell',i})]/\ell' \quad (22)$$

where C' and ℓ' pertain to a particular sample.

Figure H-3 shows transmittance as a function of wavelength for Salton Sea water and derived brines. At present, no method has been established for automated transfer of spectrophotometric data to the computer. Therefore, an approximation has been made by averaging of the data over each of 15 wavelength bands and curve-fitting the dependence on concentration with a first order polynomial.

$$k_i(C) = a_i + b_i(C) \quad (23)$$

A further approximation is made by setting either a_i or b_i to zero for all wavelength bands, thereby reflecting the rough equivalence of transmittance values only when these values are close to unity. Tabulated data for settled and filtered Salton Sea water, filtered and carbon-treated Salton Sea water, and distilled water are shown in Table H-1. Assuming that the concentration gradient varies linearly with depth,

$$C = d + e\ z \quad (24)$$

$\tau_{\ell,T}$ can be computed using data presented in Table H-1 and Eqs. (20) and (21). The path length ℓ is computed by Eq. (8) for a given depth z and time t.

The parameters remaining to be specified are the thermal properties. Data for density (ρ), thermal conductivity (k) and heat capacity (C_p) are available in the literature (M.W. Kellogg Co., 1965, and Washburn, 1926). It is convenient to curve-fit the property dependence on temperature and salt concentration. For aqueous solution of NaCl and $MgCl_2$, the density (kg/m^3) is given by

$$\begin{aligned} \rho_{NaCl} &= 16.018463\ [63.06211874 + 42.93573858\ C \\ &- 0.0075307525\ (1.8\ T - 32) - 0.0107216945\ C\ (1.8\ T - 32) + \quad (25) \\ &+ 18.25969526\ C^2 - 0.0000363288\ (1.8\ T - 32)^2] \end{aligned}$$

$$\begin{aligned} \rho_{MgCl_2} &= 1000\ (1.00522405 + 0.774055163\ C - 0.0002484006\ T \\ &+ 0.0001361628\ CT + 0.3993658493\ C^2 - 0.0000018661\ T^2) \quad (26) \end{aligned}$$

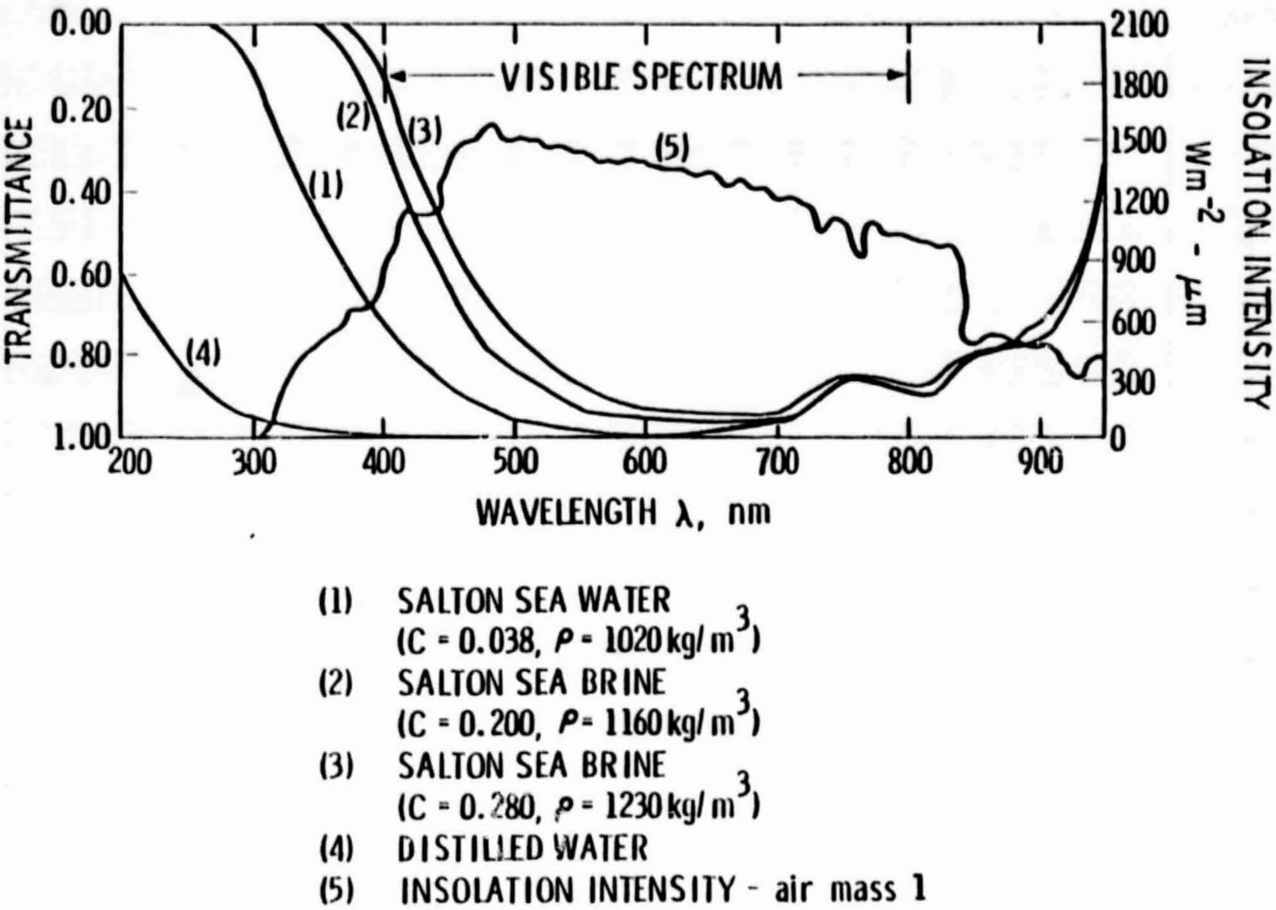


Figure H-3. Transmittance as a Function of Wavelength for Salton Sea Water and Derived Brines, 5-cm Path Length (Marsh, et al, 1981)

Table H-1. Spectral Bands and Band Extinction Coefficients[a]

Constants for Calculating Band Extinction Coefficient ($k_i = a_i + b_i C$)

Band i	Band Limits nm	Settled, Filtered Salton Sea Water $a_i(m^{-1})$	Settled, Filtered Salton Sea Water $b_i(m^{-1})$	Carbon-Treated Salton Sea Water $a_i(m^{-1})$	Carbon-Treated Salton Sea Water $b_i(m^{-1})$	Distilled Water $a_i(m^{-1})$	Distilled Water $b_i(m^{-1})$	Band Insolation Fraction f_i
1	200 - 320	0.0	1278.0	0.0	349.0	2.4	0.0	0.0005
2	320 - 370	0.0	422.0	0.0	115.0	0.7	0.0	0.0114
3	370 - 410	0.0	146.0	0.0	31.7	0.4	0.0	0.0227
4	410 - 440	0.0	64.8	0.0	14.5	0.3	0.0	0.0312
5	440 - 470	0.0	38.5	0.0	8.71	0.2	0.0	0.0420
6	470 - 500	0.0	23.1	0.0	4.68	0.1	0.0	0.0482
7	500 - 530	0.0	23.1	0.0	1.98	0.1	0.0	0.0487
8	530 - 570	0.0	8.51	0.0	0.917	0.0	0.0	0.0642
9	570 - 720	0.0	4.88	0.0	1.24	0.4	0.0	0.2296
10	720 - 830	2.7	0.0	2.7	0.0	2.7	0.0	0.1276
11	830 - 910	5.0	0.0	5.0	0.0	5.0	0.0	0.0749
12	910 - 940	10.3	0.0	10.3	0.0	10.3	0.0	0.0102
13	940 - 1,040	32.6	0.0	32.6	0.0	32.6	0.0	0.0796
14	1,040 - 1,110	15.4	0.0	15.4	0.0	15.4	0.0	0.0437
15	1,110 - 1,200	51.3	0.0	51.3	0.0	51.3	0.0	0.0282

[a]Source: Marsh, et al, 1981.

The thermal conductivity, k (W/m-°C) is given

$$k = 0.587\ [1 + 0.00281\ (T - 20)]\ (1 - \alpha_{SALT}C) \tag{27}$$

where α_{SALT} = 0.00248 for NaCl and 0.00488 for $MgCl_2$.

The heat capacity, C_p (W - s/kg - °C) is given by

$$C_p^{NaCl} = 4184\ (1.007464361 - 1.396381346\ C - 0.0001150635\ T + 0.0014280276\ CT + 1.742790998\ C^2 + 0.0000005143\ T^2) \tag{28}$$

and by

$$C_p^{MgCl_2} = 4184\ (C^o_p + AT);\ C^o_p = 1.00070 - 1.6746\ C + 1.44\ C^2 \tag{29}$$

where

$$A = \begin{cases} 0.1 + 39\ C & \text{for } C < 0.15 \\ 2.8 + 20\ C & \text{for } 0.15 \leq C < 0.17 \\ 4.5 + 10\ C & \text{for } 0.17 \leq C < 0.20 \\ 6.5 & \text{for } 0.20 \leq C < 0.24 \\ 8.489 - 8.2\ C & \text{for } 0.24 \leq C \end{cases} \tag{30}$$

Ground thermal properties are known with less accuracy. Ormat suggests using the same thermal conductivity as saline water. Soil conductivity is dependent upon the type of soil and varies over a wide range. (Eckert and Drake, 1972) For example at 20°C, the conductivity of sandstone is about four times that of coarse gravelly earth and three times that of saline water. The JPL code is programmed to accept a temperature dependent range of soil thermal conductivities.

H.1.4 Comparison of JPL, Ormat and SERI Model Results

A comparison of the JPL model and the SERI "SOLPOND" (Jayadev and Henderson, 1977) model results for electrical output at Sevier Lake, Utah and Danby Lake, California was compiled by the Bureau of Reclamation (1981). The data are reproduced here in Table H-2. The agreement between the two sets of predictions is remarkably good in spite of coding and input differences.

A comparison was also made of JPL and Ormat (Ormat using their own in-house program) estimates for solar pond thermal output for apartment space and domestic water heating in Madison, Wisconsin; Seattle, Washington; and Phoenix, Arizona. The results are tabulated in Table H-3. The Ormat and JPL model runs assumed a water clarity equivalent to Ormat Water Type #2 (continental slope water). As shown there is a reasonable agreement in

Table H-2. Comparison of JPL and SERI Solar Pond Model Results[a] (Units are MW/km^2)

	Sevier Lake		Danby Lake	
	SERI	JPL	SERI	JPL
Thermal Energy	37.1	41.2	50.0	50.2
Gross Electrical Energy	4.0	3.8	4.8	4.5
Net	3.1	3.0	3.7	3.4

[a]Source: Bureau of Reclamation, U.S. DOI, (1981)

estimates of annual-average thermal output. The discrepancy results from several factors, including model coding and input differences, different thermal ground properties. The Ormat code assumes that the ground thermal conductivity is that of brine at a given temperature. The JPL value is three times the Ormat value and therby appears to more closely match literature values for ground thermal conductivity.

For the Madison case, two JPL runs were made, one with and one without allowance for formation of a thin, opaque ice cover when the average daily ambient temperature is below -6°C. The ice cover has a duration of approximately 55 days, during which time no insolation penetrates the pond surface. The annual-average thermal outputs from these runs are 6.4 Wth/m^2 and 9.3 Wth/m^2, respectively, as compared to 10 Wth/m^2 from the Ormat run.

JPL and Ormat model results are summarized in Table H-4 for a "near-baseload" electrical solar pond at the Salton Sea in California. Water optical clarity is assumed to be that of Ormat Water Type #2 (continental slope) and #3 (continental shelf). The ground thermal conductivity for all runs is assumed to be that of saline water, except as noted. Considering the many model assumptions, the two sets of results appear to be in reasonable agreement. Carbon-treatment of Salton Sea water produces an optical quality between Type #2 and Type #3 waters. The JPL code estimates a net electrical output of 3.43 We/m^2. The output rate is sensitive to the ground conductivity and reduces to 2.98 We/m^2 when the conductivity is increased by a factor of 3 (Table H-4).

Table H-3. Comparison of Thermal Output Estimates from JPL and Ormat Models

Application	Site	Area (m^2)	Depth(m)	Minimum Temperature	Water Type	Average Annual Output Ormat	Average Annual Output JPL
						Wth/m^2	
Apartment Space and Domestic Water Heating	Madison	21776	4.55	$65.6^{\circ}C$	Ormat #2[a]	10.0	6.4[b]
							9.3[c]
	Seattle	29896	5.05	$65.6^{\circ}C$	Ormat #2	5.5	4.8
	Phoenix	2072	5.05	$65.6^{\circ}C$	Ormat #2	43.4	43.5

[a]Ormat Water Type #2 is continental slope water.
[b]With allowance for formation of a thin opaque ice cover.
[c]No ice cover assumed.

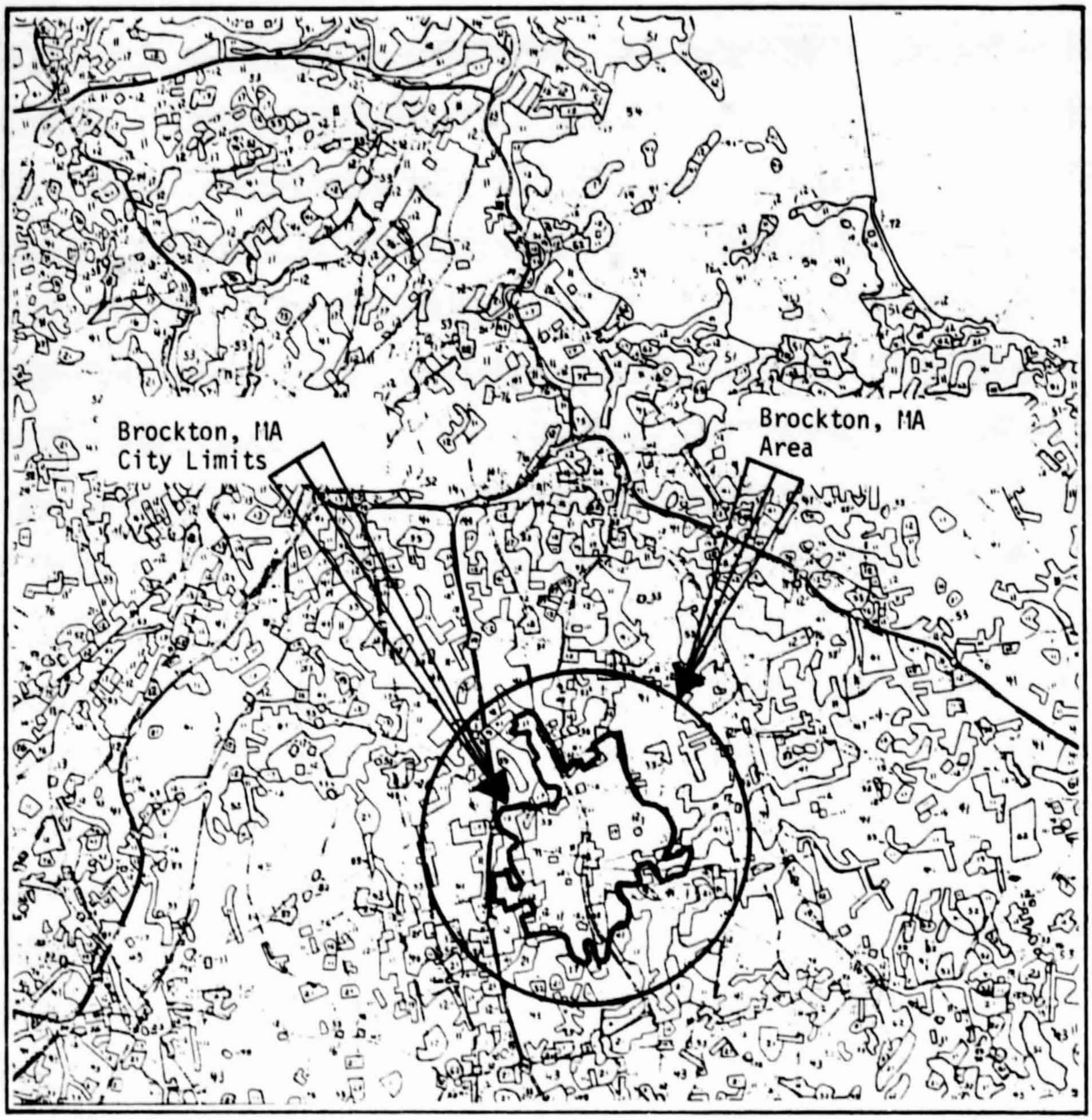
APPENDIX I

LAND-USE MAPS

COMPILED BY THE BENHAM GROUP, OKLAHOMA CITY, OKLAHOMA, 1982

Table I-1. Land-Use Map: Legend

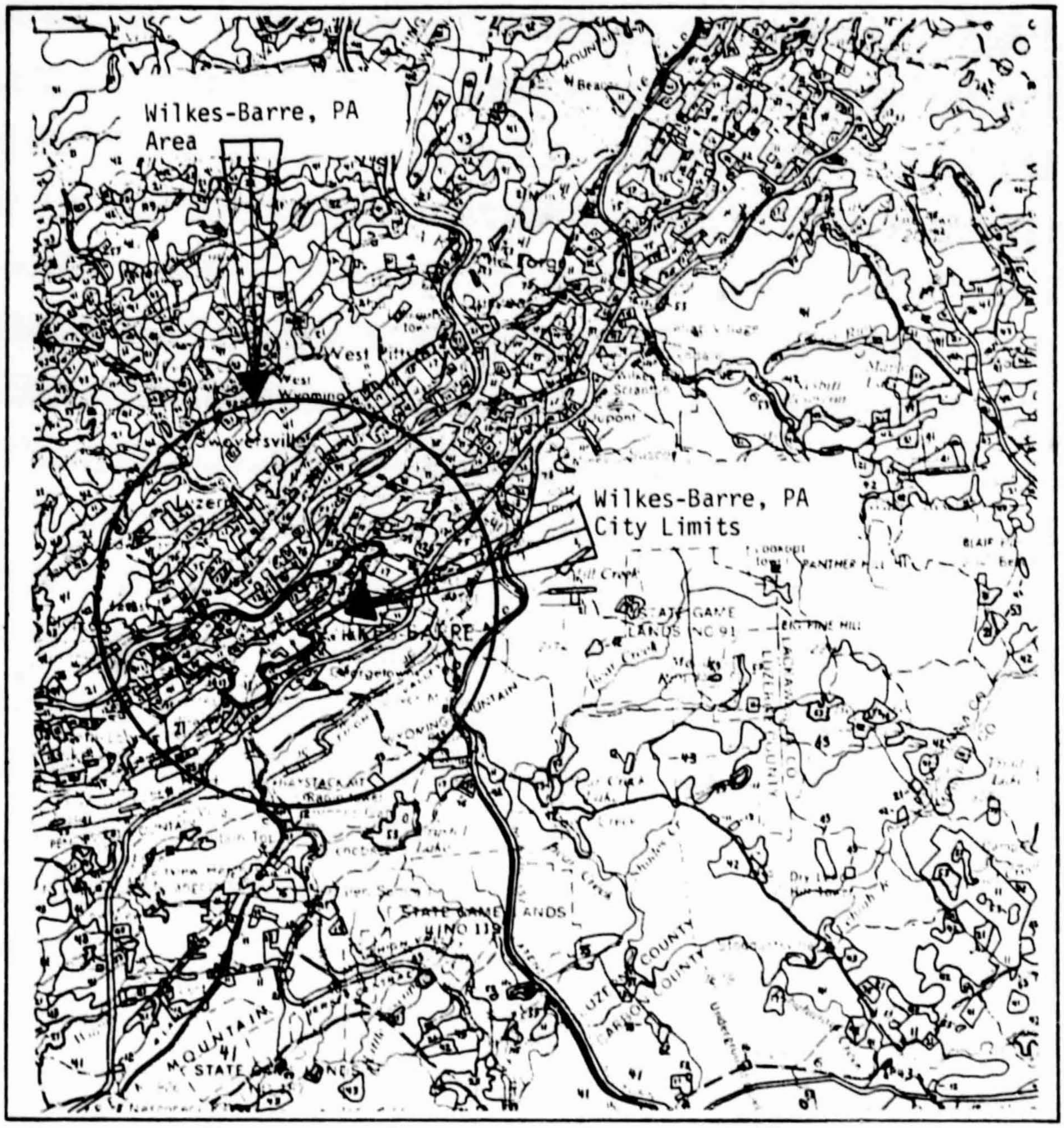
1	Urban of Built-Up Land	5	Water
11	Residental	51	Streams and canals
12	Commercial and services	52	Lakes
13	Industrial	53	Reservoirs
14	Transportation, communications and utilities	54	Bays and estuaries
15	Industrial and commercial complexes		
16	Mixed urban or built-up land	6	Wetland
17	Other urban or built-up land		
		61	Forested wetland
		62	Nonforested wetland
2	Agricultural Land		
21	Cropland and pasture	7	Barren Land
22	Orchards, groves, vineyards, nurseries, and ornamental horticultural areas	71	Dry salt flats
		72	Beaches
23	Confined feeding operations	73	Sand areas other than beaches
24	Other agricultural land	74	Bare exposed rocks
		75	Strip mines, quarries, and gravel pits
		76	Transitional areas
3	Rangeland		
31	Herbaceous rangeland		
32	Shrub and brush rangeland		
33	Mixed rangeland	8	Tundra
		81	Shrub and brush tundra
		82	Herbaceous tundra
4	Forest Land	83	Bare ground tundra
		84	Wet tundra
41	Deciduous forest land	85	Mixed tundra
42	Evergreen forest land		
43	Mixed forest land		
		9	Perennial Snow or Ice
		91	Perennial snowfields
		92	Glaciers



Source: USGS 1979b.

Scale: 1:250,000

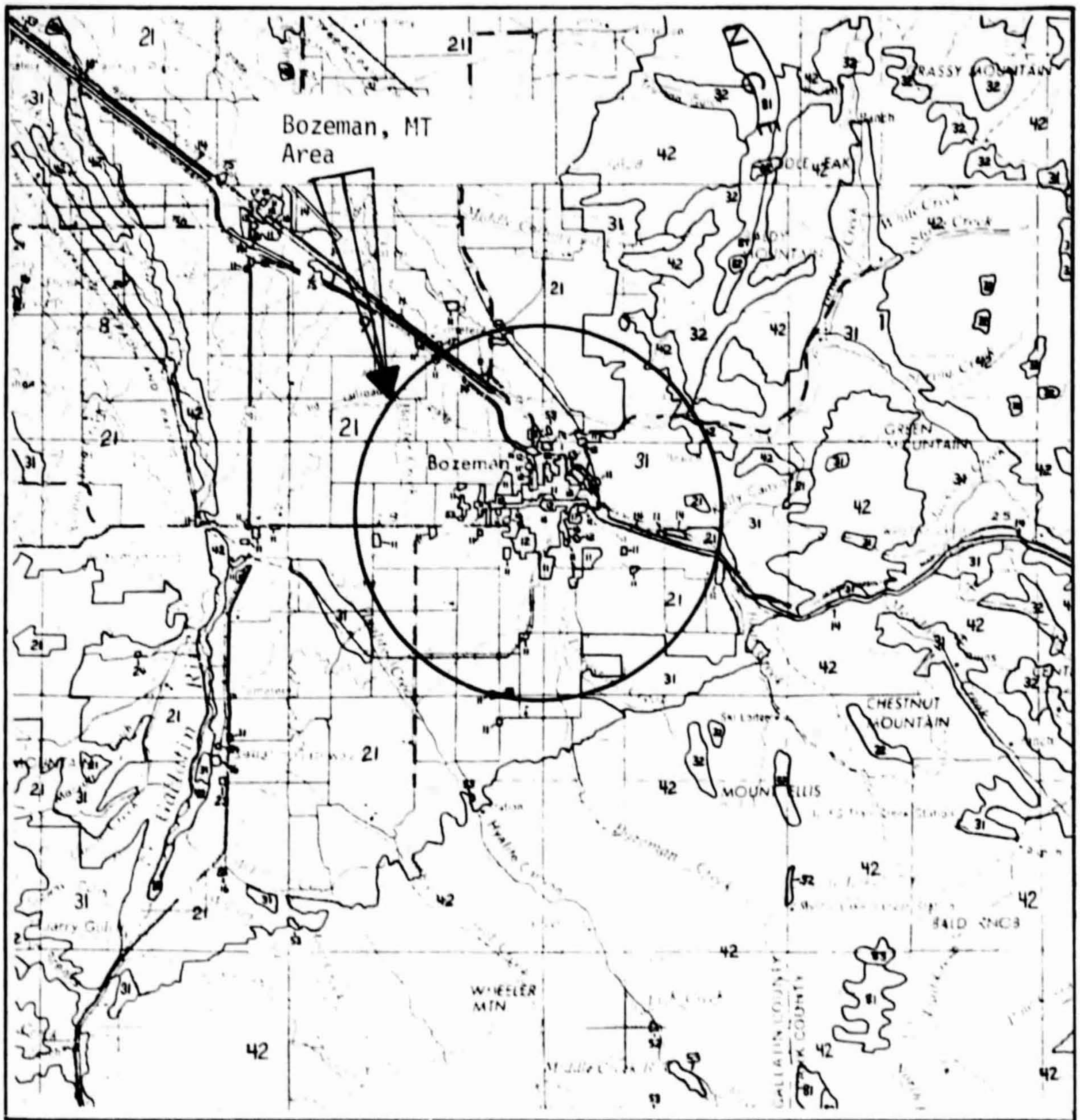
Figure I-1. Land-Use/Land-Cover Map for Brockton, Mass.



Source: USGS 1979j.

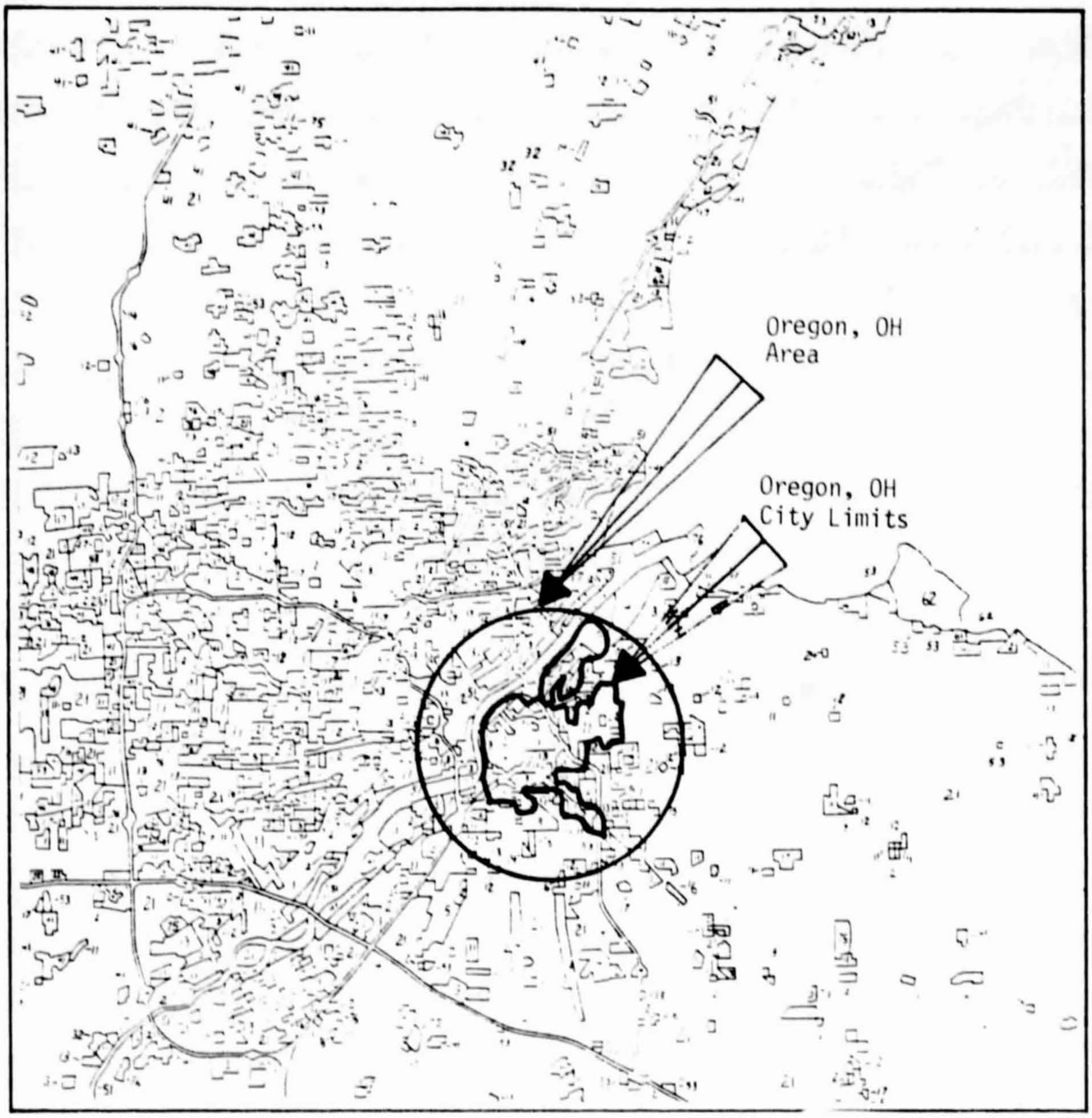
Scale: 1:250,000

Figure I-2. Land-Use/Land-Cover Map for Wilkes-Barre, Pa.



Source: USGS 1980a. Scale: 1:250,000

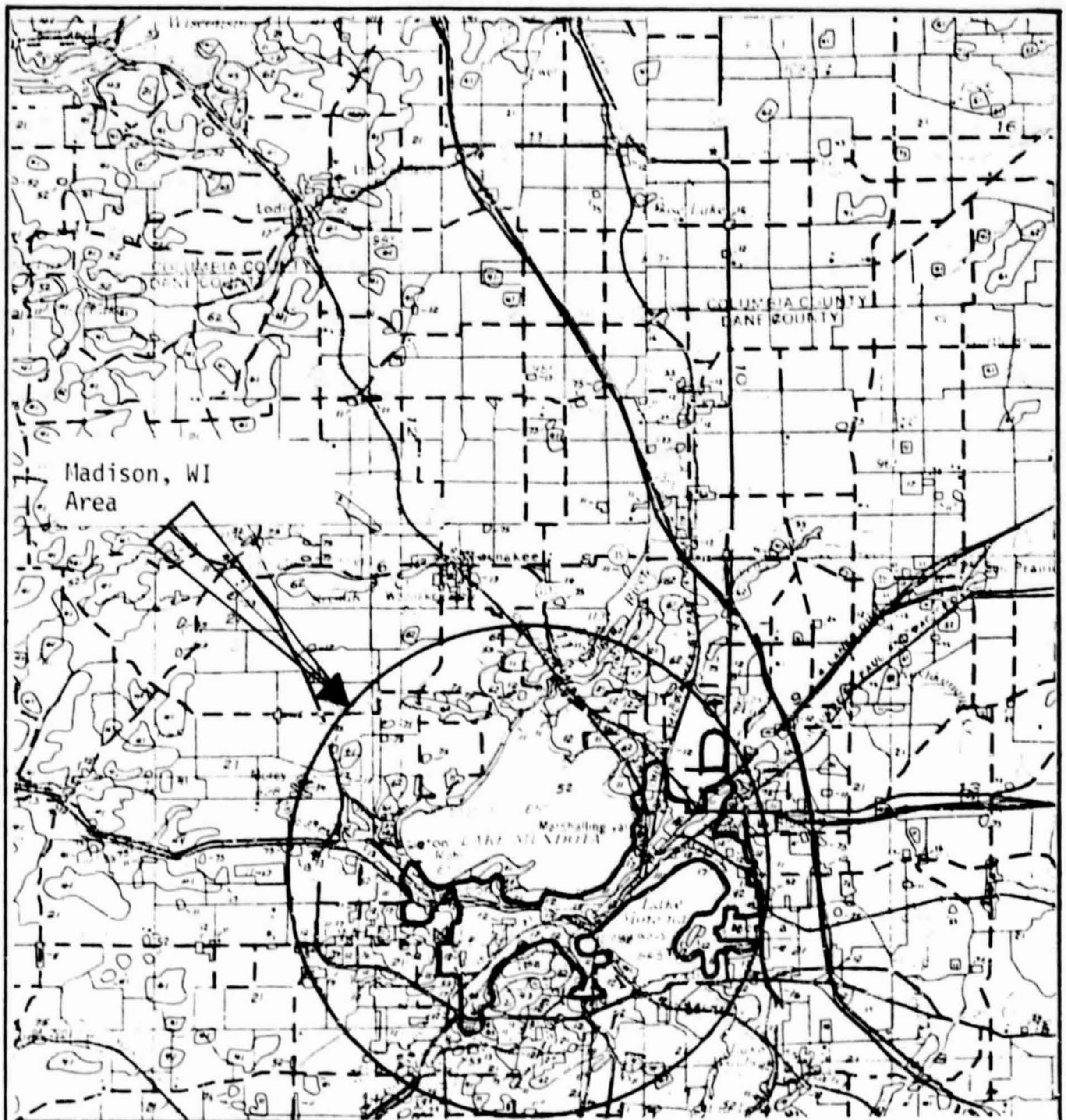
Figure I-3. Land-Use/Land-Cover Map for Bozeman, Mont.



Source: USGS 1979m.

Scale: 1:250,000

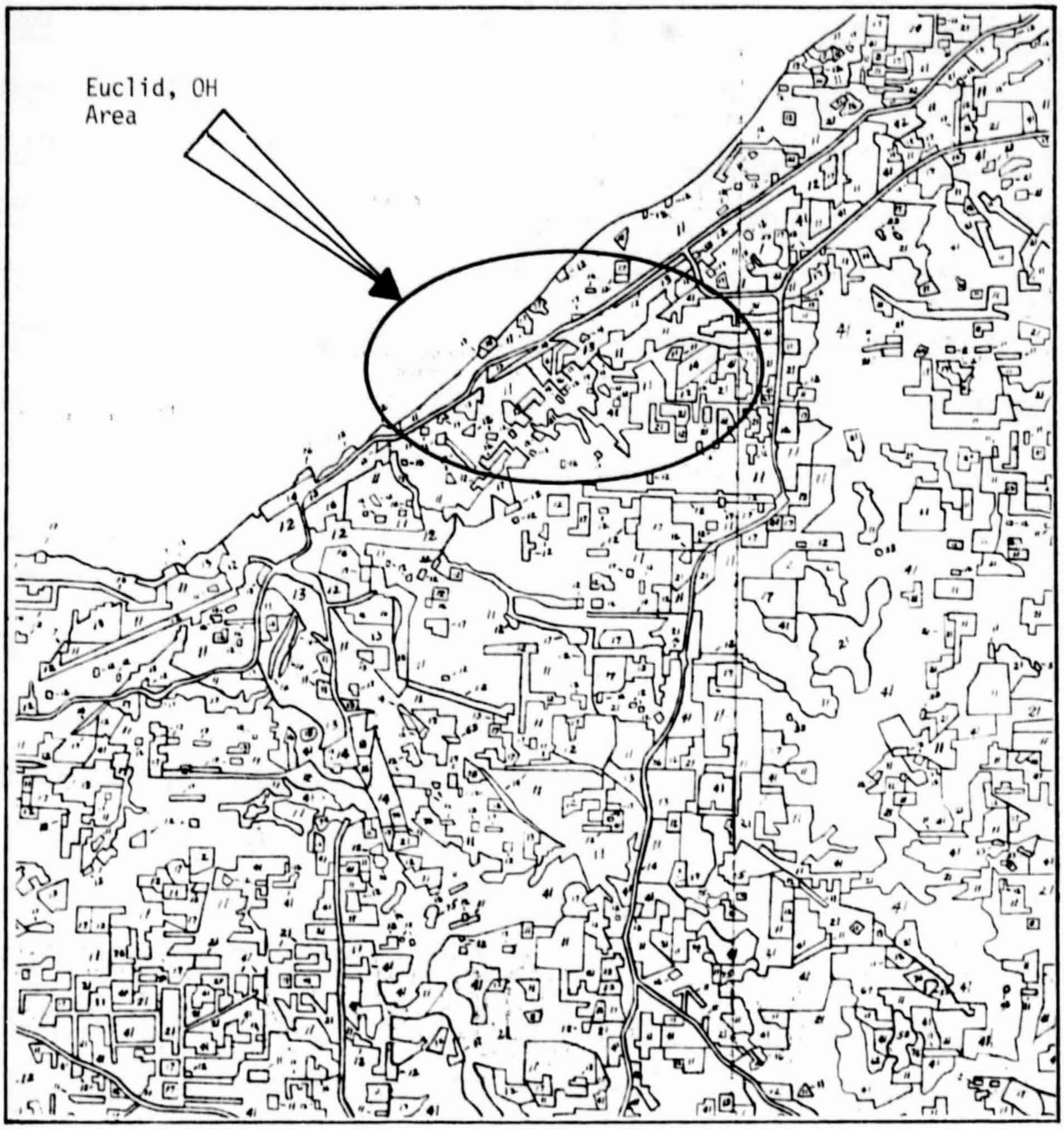
Figure I-4. Land-Use/Land-Cover Map for Oregon, Ohio



Source: USGS 1980c.

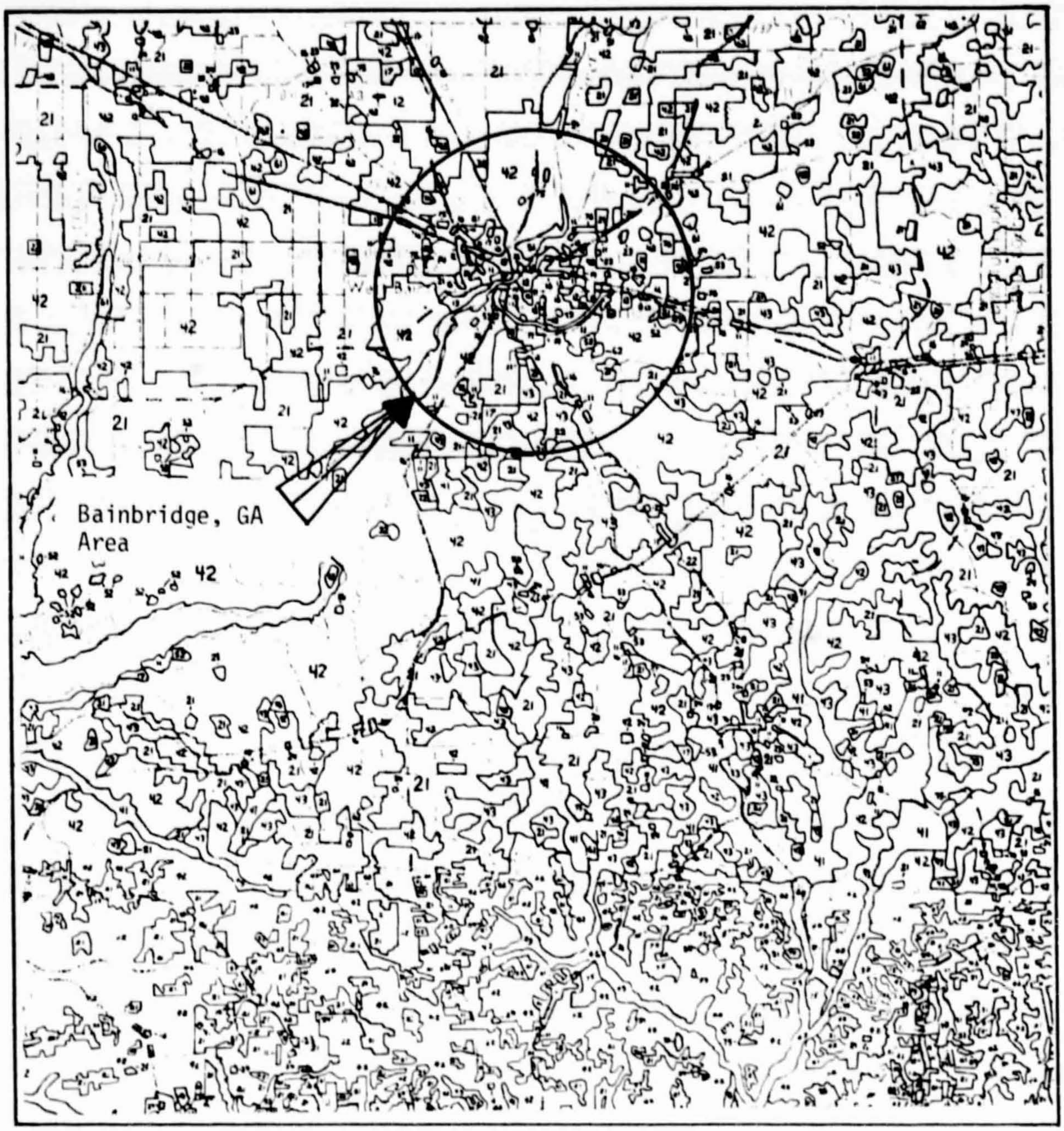
Scale: 1:250,000

Figure I-5. Land-Use/Land-Cover Map for Madison, Wis.



Source: USGS 1979c. Scale: 1:250,000

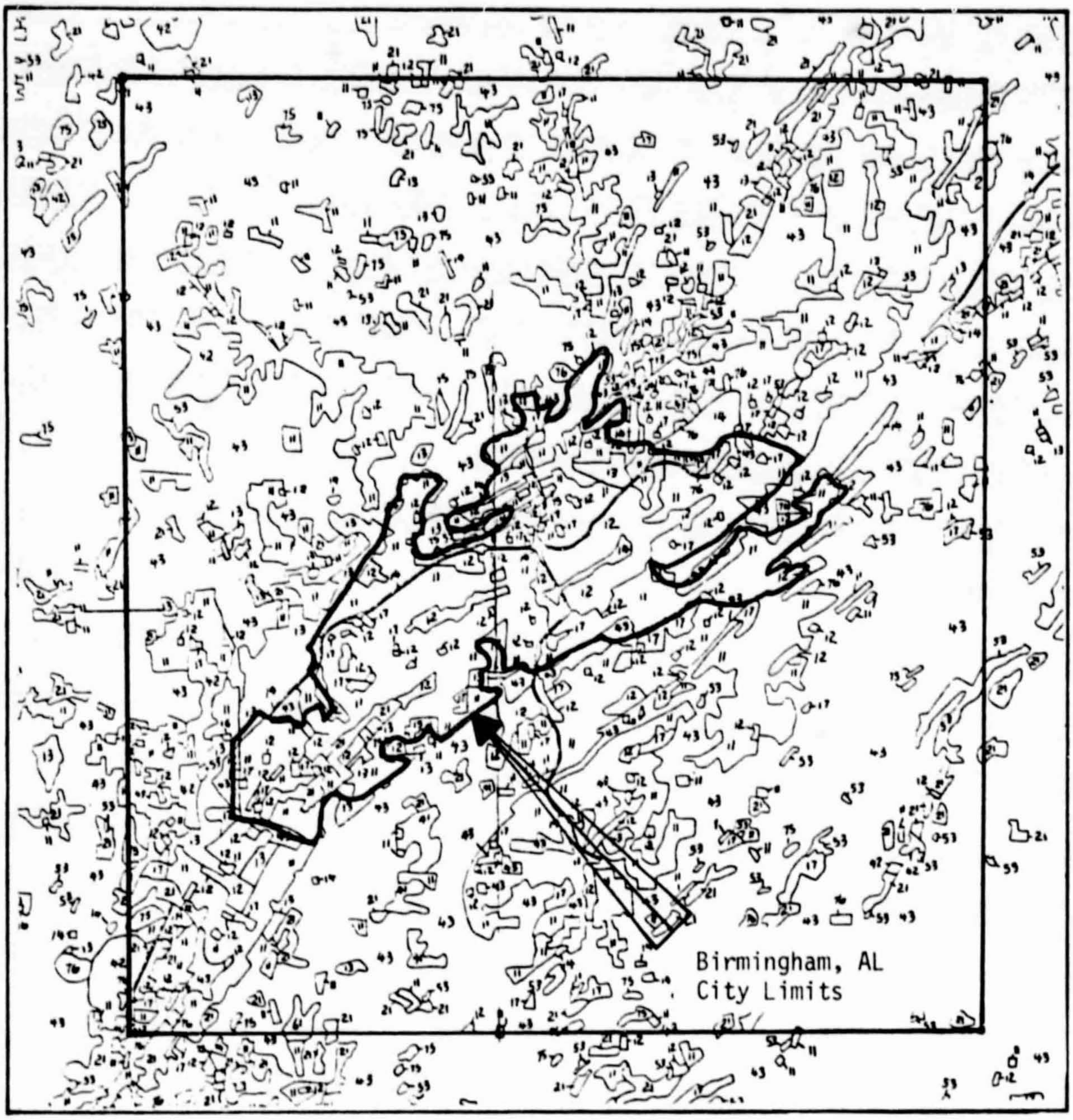
Figure I-6. Land-Use/Land-Cover Map for Euclid, Ohio



Source: USGS 19791.

Scale: 1:250,000

Figure I-7. Land-Use/Land-Cover Map for Bainbridge, Ga.



Source: USGS 1979a.

Scale: 1:250,000

Figure I-8. Land-Use/Land-Cover Map for Birmingham, Ala.

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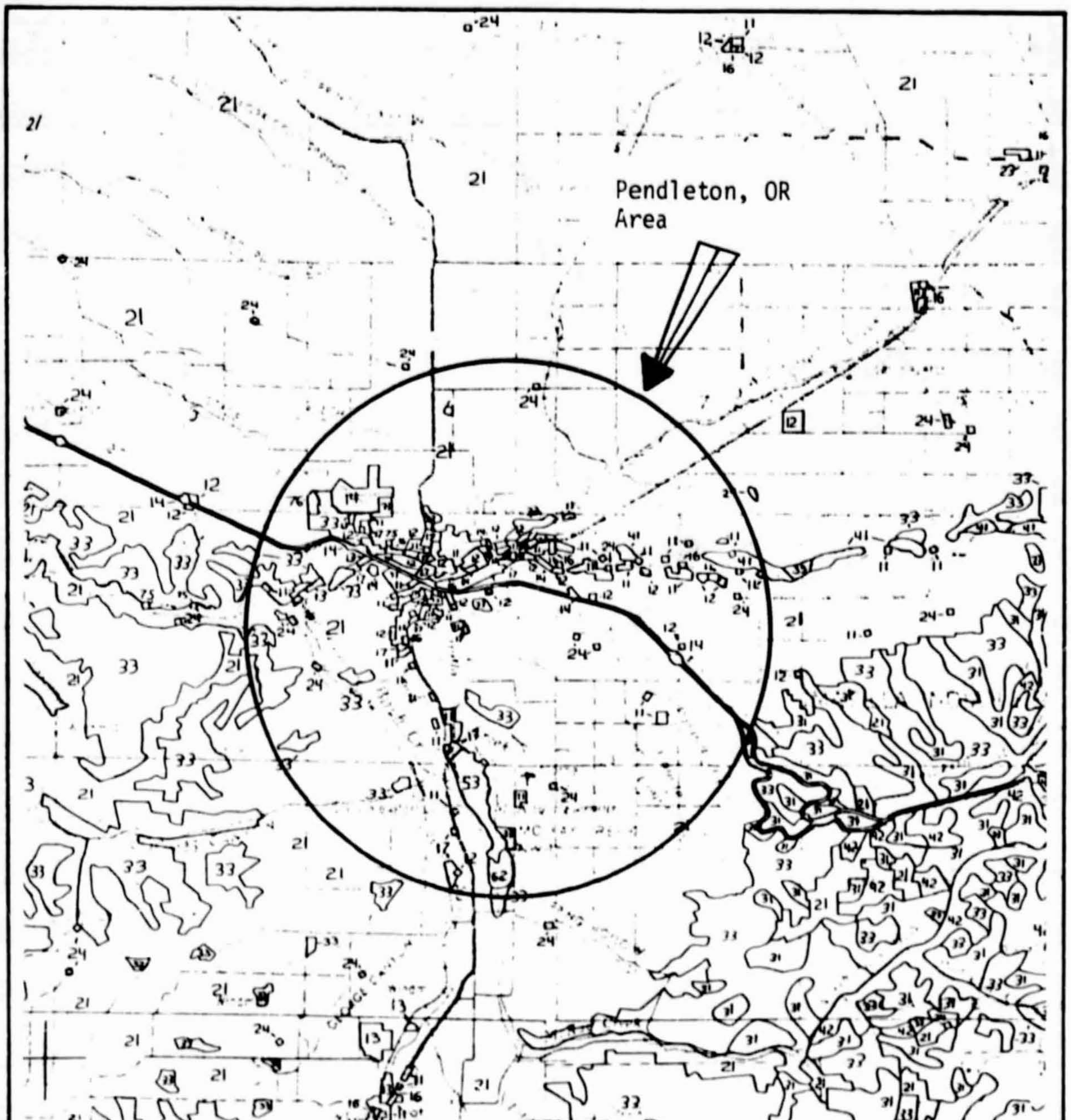
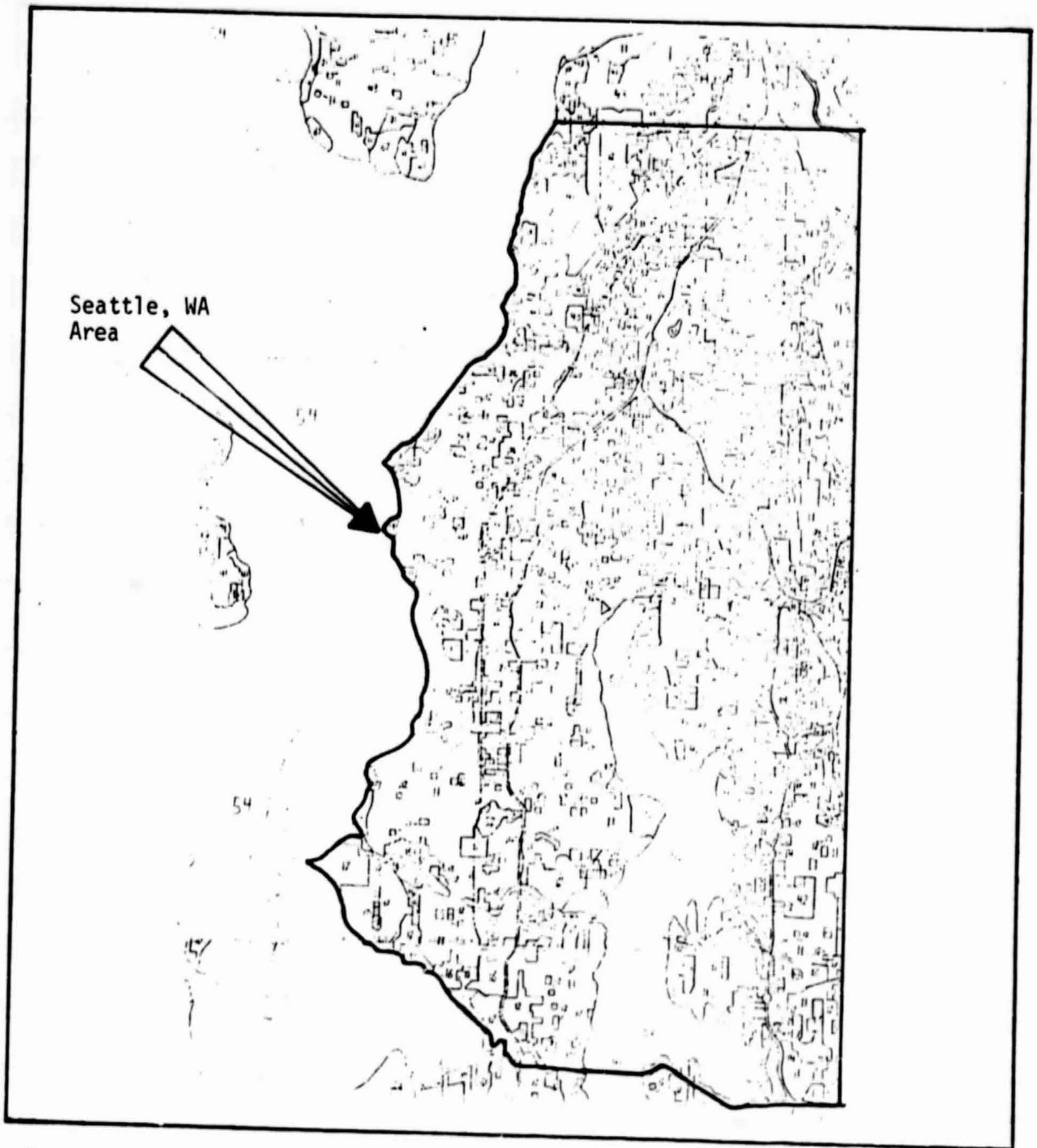


Source: USGS 1980d. Scale: 1:250,000

Figure I-9. Land-Use/Land-Cover Map for Pendleton, Oreg.



Source: USGS 1979k.

Scale: 1:100,000

Figure I-10. Land-Use/Land-Cover Map for Seattle, Wash.

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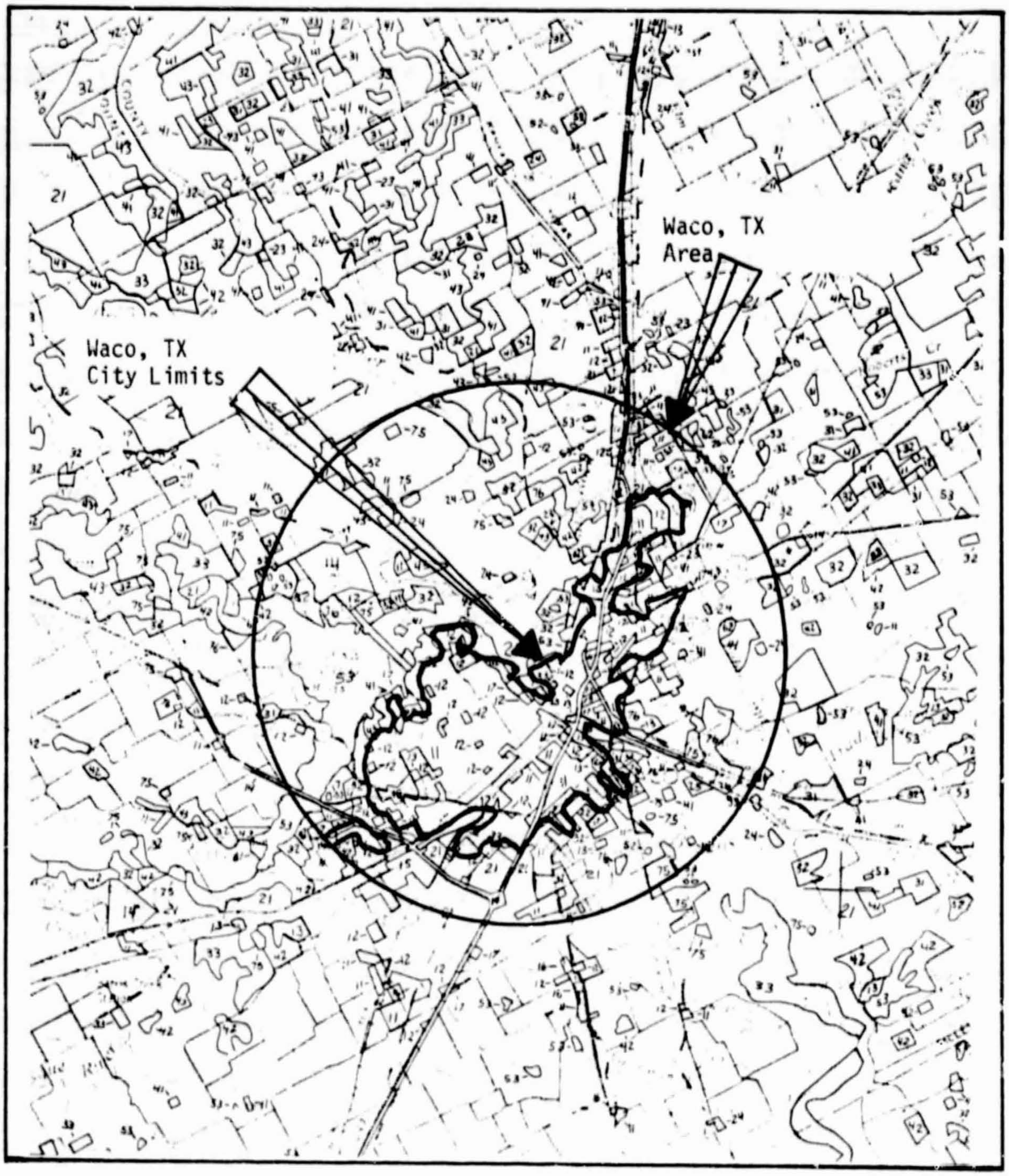
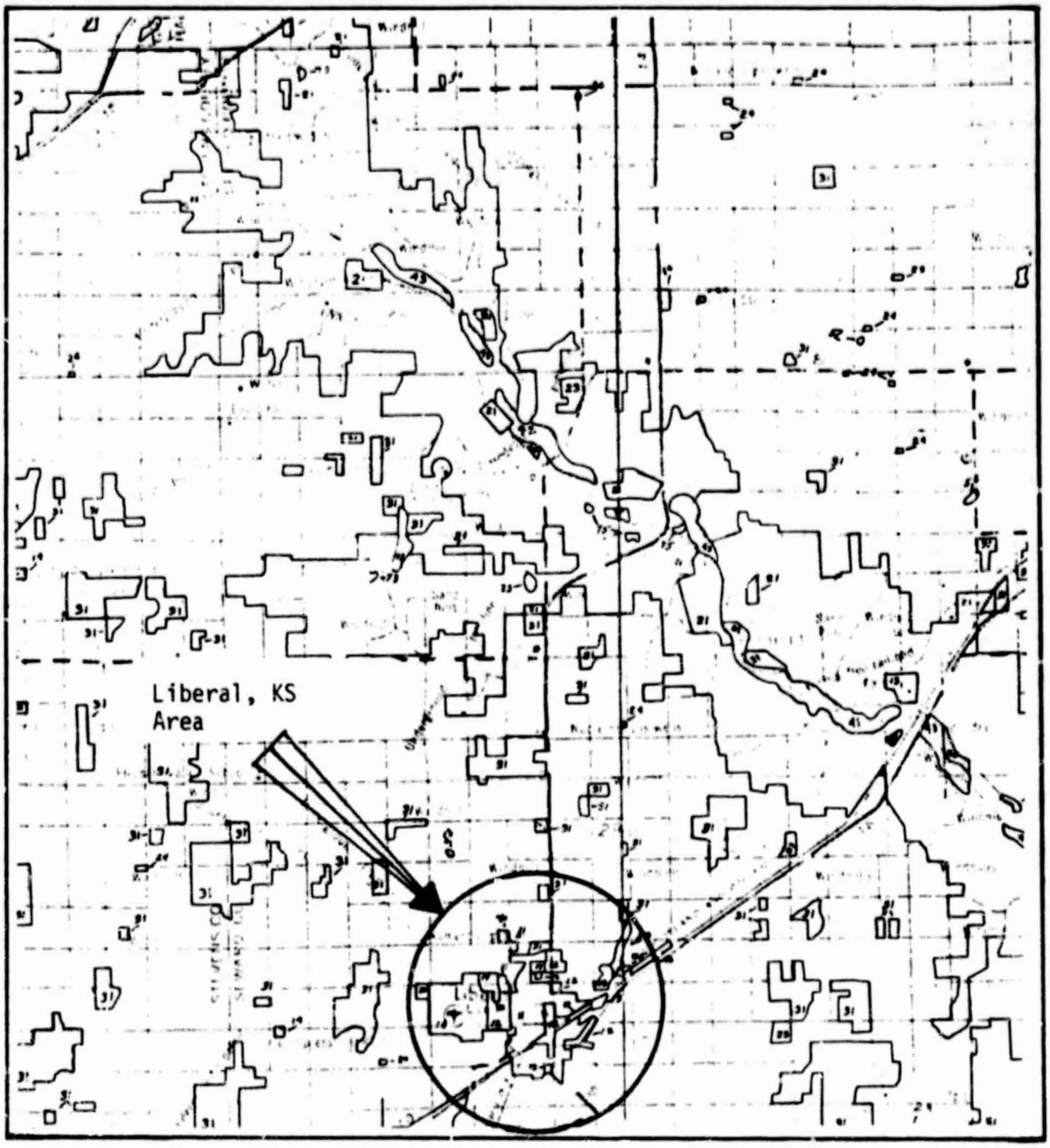


Source: USGS 1980e.

Scale: 1:250,000

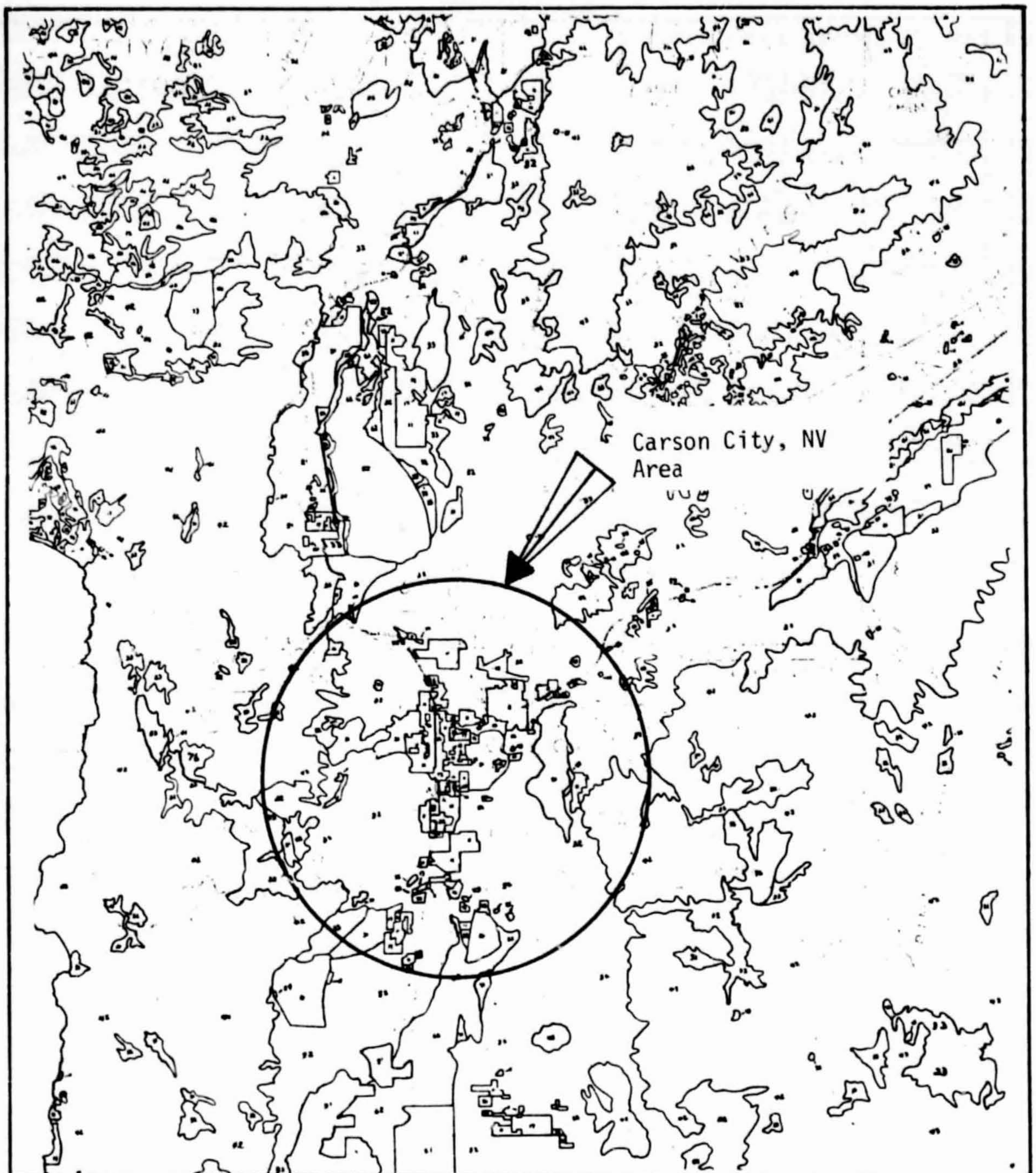
Figure I-11. Land-Use/Land-Cover Map for Waco, Tex.



Source: USGS 1979d.

Scale: 1:250,000

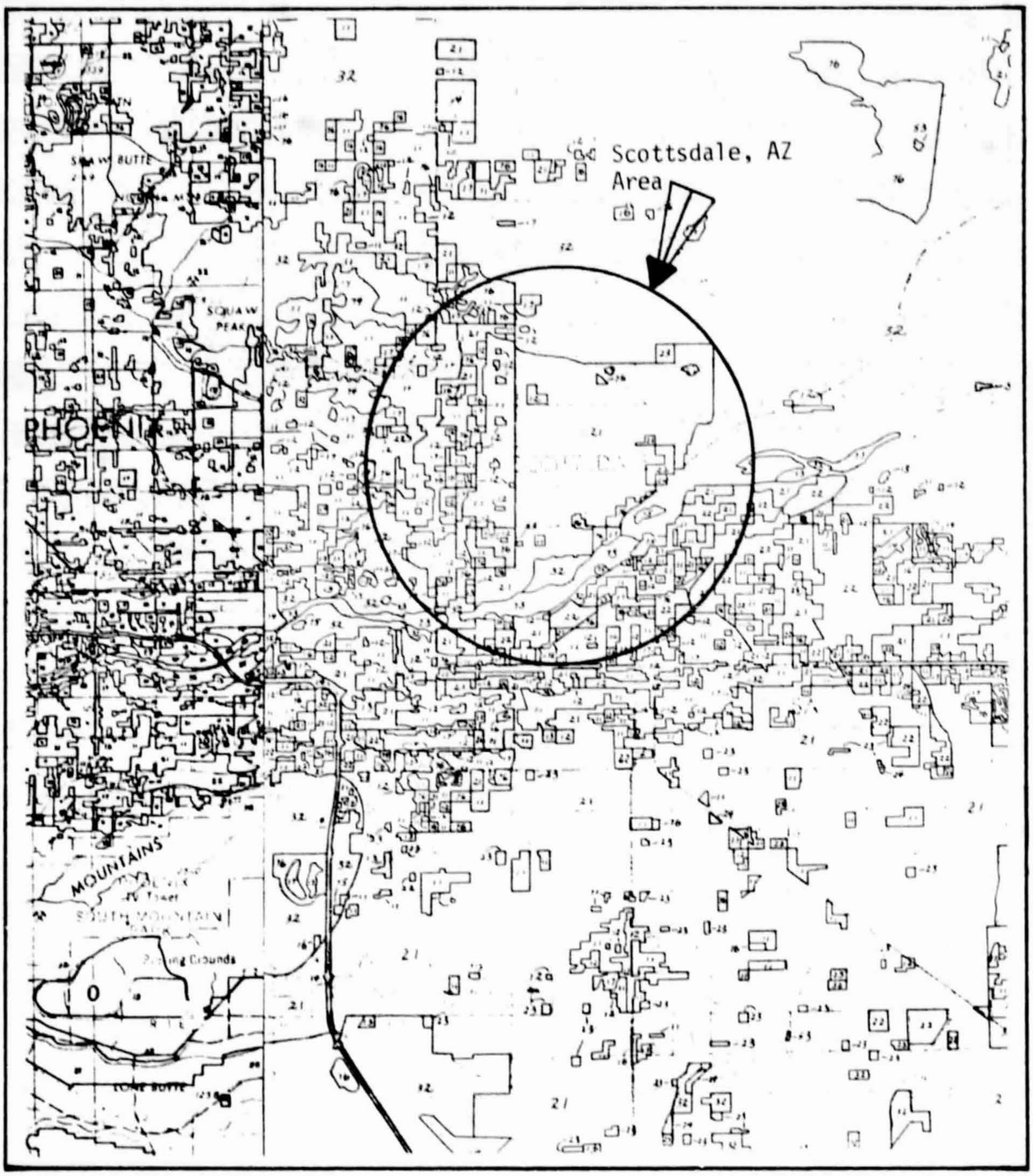
Figure I-12. Land-Use/Land-Cover Map for Liberal, Kans.



Source: USGS 1979h.

Scale: 1:250,000

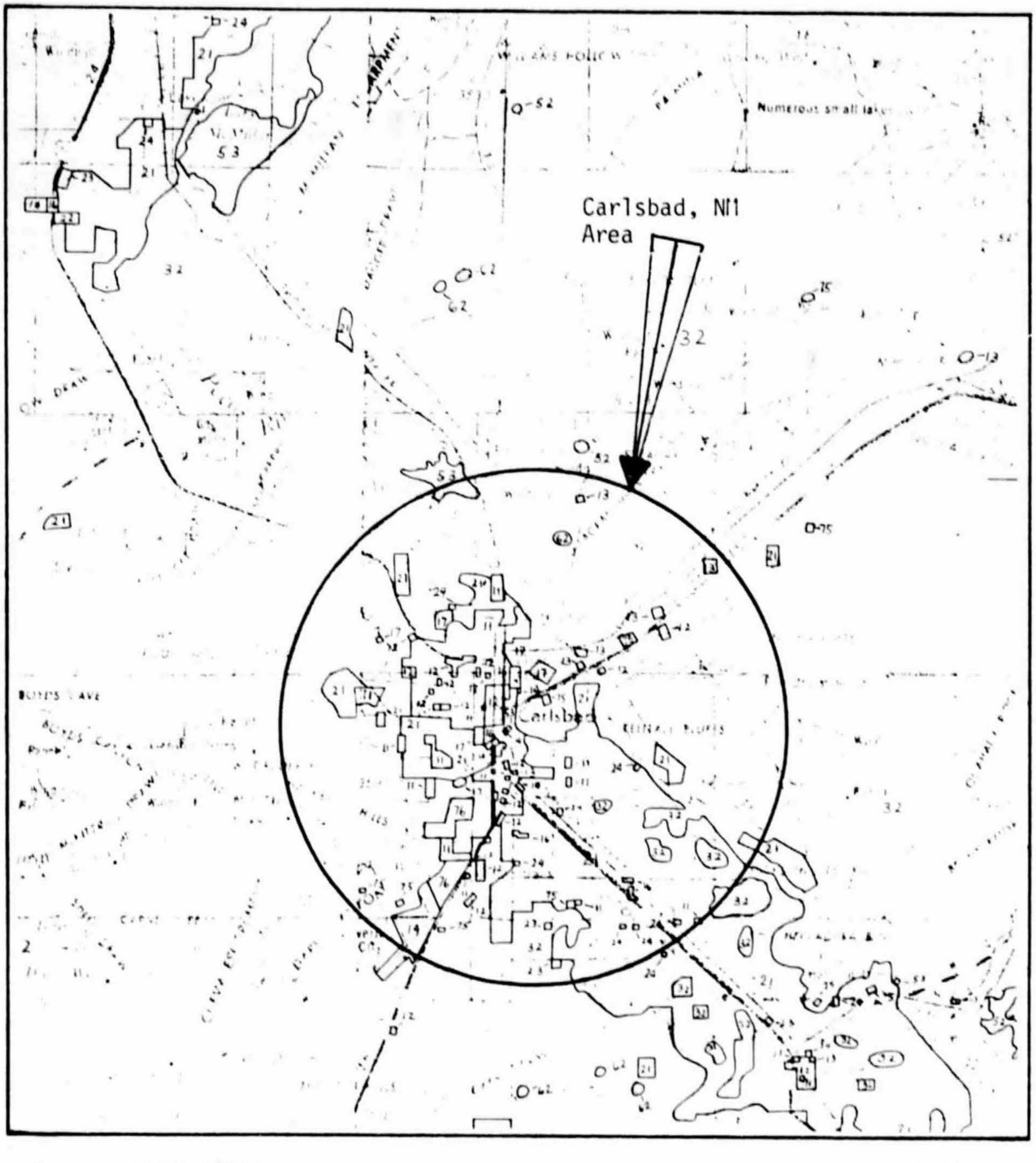
Figure I-13. Land-Use/Land-Cover Map for Carson City, Nev.



Source: USGS 1979f;
1979g.

Scale: 1:250,000

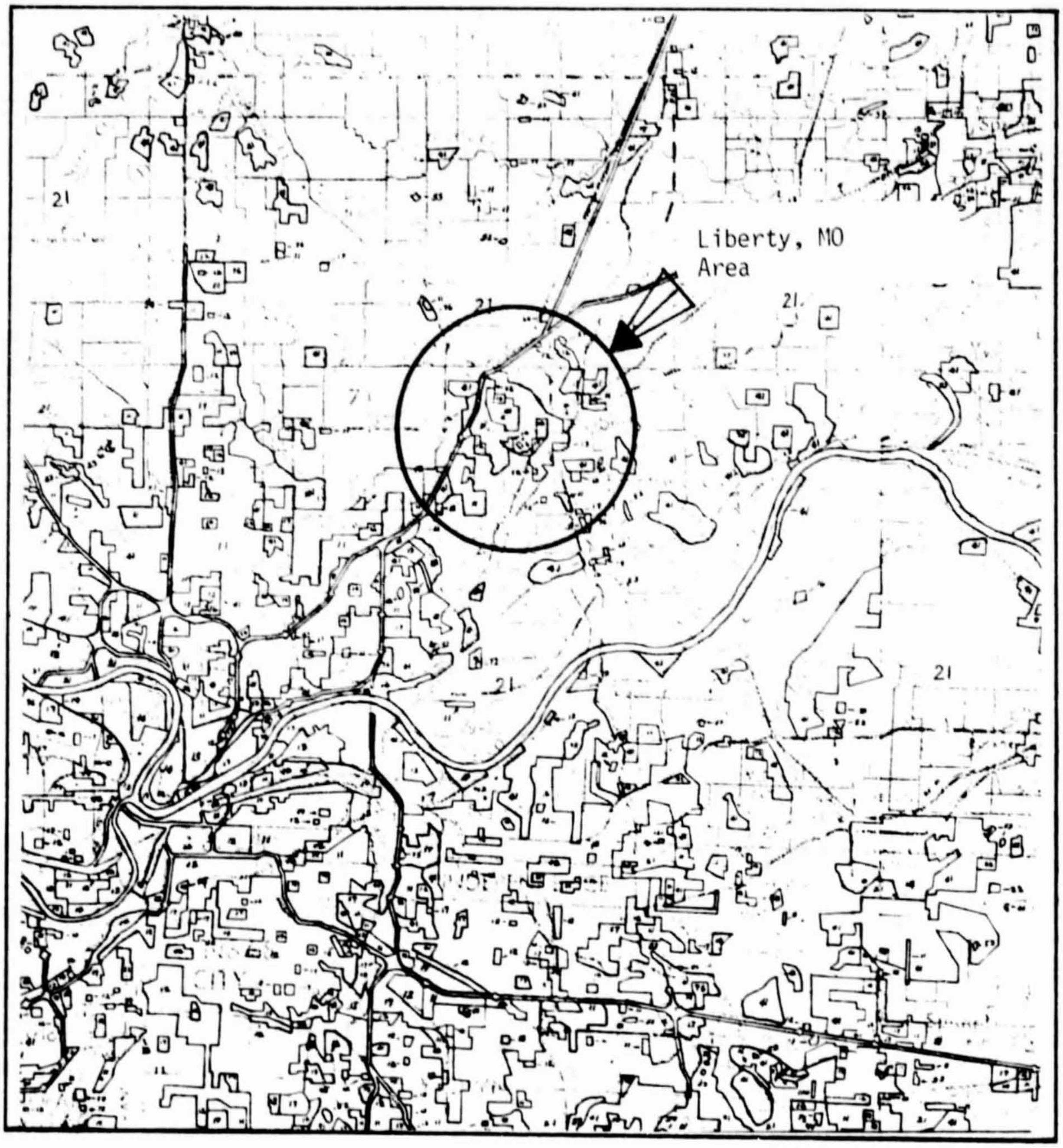
Figure I-14. Land-Use/Land-Cover Map for Scottsdale, Ariz.



Source: USGS 1980b.

Scale: 1:250,000

Figure I-15. Land-Use/Land-Cover Map for Carlsbad, N.Mex.



Source: USGS 1979e.

Scale: 1:250,000

Figure I-16. Land-Use/Land-Cover Map for Liberty, Mo.

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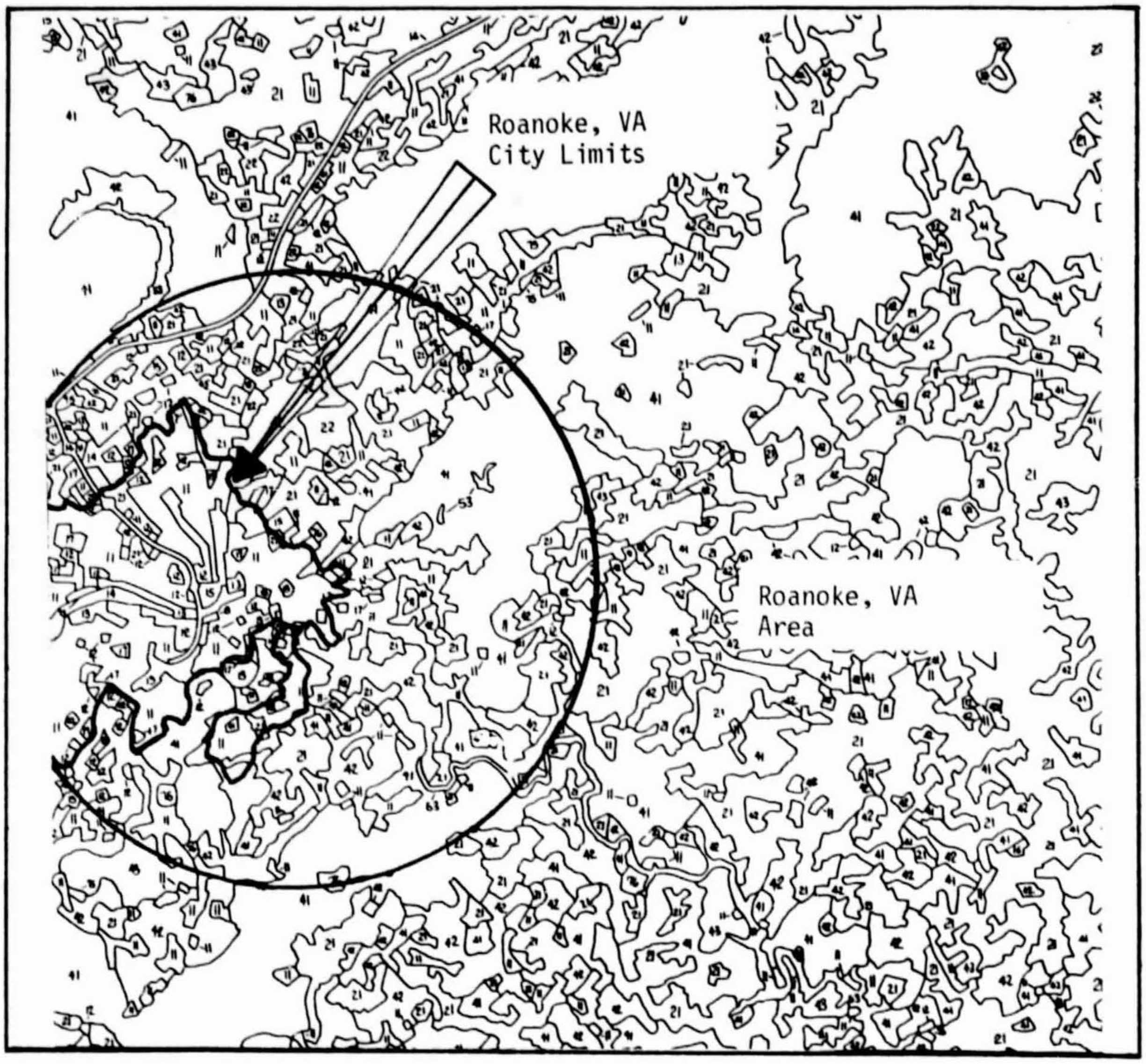

Source: USGS 1979i.

Scale: 1:250,000

Figure I-17. Land-Use/Land-Cover Map for Roanoke, Va.

APPENDIX J

INDUSTRIAL PROCESS HEAT SECTOR

J.1 INDUSTRIAL PROCESS HEAT SECTOR: LOW TEMPERATURE THERMAL ENERGY USE BY STATE AND REGION

Table J-1. Distribution of Energy Used by 2-Digit SIC Code and State (10^{12}Btu)

REGION	SIC 20 Total Thermal	SIC 20 200°F Thermal	SIC 25 Total Thermal	SIC 25 200°F Thermal	SIC 26 Total Thermal	SIC 26 200°F Thermal	SIC 28 Total Thermal	SIC 28 200°F Thermal	SIC 31 Total Thermal	SIC 31 200°F Thermal	SIC 32 Total Thermal	SIC 32 200°F Thermal	SIC 33 Total Thermal	SIC 33 200°F Thermal
PACIFIC NORTHWEST														
Washington	18.1	4.	.2	-	51.9	1.9	10.0	-	-	-	9.1	.1	17.2	.1
Oregon	7.5	2.1	.2	.2	25.2	3.7	4.7	-	-	-	8.7	.2	8.2	.3
Idaho	20.7	8.0	-	-	-	-	3.6	-	-	-	2.8	.5	-	-
Subtotal	46.3	14.4	0.4	.2	77.1	5.6	18.3	-	0	-	20.6	.8	25.4	.4
SALT LAKE														
N. California	39.7	13.3	-	-	15.0	2.2	26.3	2.2	-	-	15.2	.1	9.4	.2
Colorado	19.9	2.5	-	-	0.8	-	2.1	-	-	-	14.0	.1	8.9	-
Utah	3.3	1.1	-	-	-	-	2.0	-	-	-	9.2	-	25.8	-
Nevada	0.6	-	-	-	-	-	-	-	-	-	6.9	.3	2.4	-
Subtotal	63.5	6.9	0	-	15.8	2.2	30.4	2.2	0	0	45.3	.5	46.5	.2
SOUTHWEST														
Arizona	4.0	.6	-	-	-	-	2.9	-	-	-	7.6	-	30.4	-
New Mexico	1.1	.3	-	-	-	-	-	-	-	-	3.6	.2	-	-
S. California	50.5	19.7	1.6	.9	16.0	1.8	27.6	2.8	-	-	84.2	.7	33.7	.7
Subtotal	55.6	20.6	1.6	.9	16.0	1.8	30.5	2.8	0	0	95.4	.9	64.1	.7
RED RIVER														
Texas	35.3	15.	1.1	.7	42.2	2.6	738.3	22.6	-	-	93.4	1.3	76.0	1.0
Kansas	10.5	3.7	0.1	-	2.4	-	27.2	-	-	-	22.8	-	1.2	.4
Oklahoma	3.7	1.7	0.1	.1	-	-	18.8	-	-	-	19.7	0.1	4.0	-
Subtotal	49.3	20.6	1.3	.8	44.6	2.6	784.3	27.6	0	0	135.9	1.4	81.2	1.4
BLACK HILLS														
Montana	4.2	3.4	-	-	-	-	-	-	-	-	6.9	.2	-	-
Wyoming	3.5	-	-	-	-	-	-	-	-	-	3.5	-	-	-
N. Dakota	7.8	.5	-	-	-	-	-	-	-	-	-	-	-	-
S. Dakota	2.9	2.1-	-	-	-	-	-	-	-	-	1.9	-	-	-
Nebraska	21.2	7.4	-	-	0.2	-	13.4	-	-	-	8.5	.1	2.1	-
Subtotal	39.6	13.4	0	0	0.2	0	13.4	0	0	0	20.8	.3	2.1	0

Table J-1. Distribution of Energy Used by 2-Digit SIC Code and State (10^{12}Btu) (Cont'd)

REGION	SIC 20		SIC 25		SIC 26		SIC 28		SIC 31		SIC 32		SIC 33	
	Total Thermal	200°F Thermal	Total Thermal	200°F Thermal	Total Thermal	200°F Thermal	Total Thermal	200°F Thermal	Total Thermal	200°F Thermal	Total Thermal	200°F Thermal	Total Thermal	200°F Thermal
GREAT LAKES														
Minnesota	38.5	1.5	0.3	-	22.2	2.5	4.3	-	0.3	-	7.6	.1	4.7	.2
Iowa	55.9	23.3	0.4	-	3.1	-	27.5	-	0.2	-	27.2	.4	8.3	.5
Wisconsin	35.7	17.7	1.2	.8	88.9	12.5	7.6	.2	2.2	1.9	7.3	.3	14.3	2.1
Illinois	76.2	38.8	2.5	1.0	22.4	1.3	82.1	9.7	0.6	0.3	50.1	0.9	154.2	2.3
Michigan	22.0	8.9	3.1	.6	51.0	7.4	62.6	4.5	0.7	.7	54.4	.7	156.8	7.4
Indiana	26.4	10.3	2.2	1.5	8.8	.9	24.5	0.1	0.1	-	48.0	0.8	250.6	1.7
Ohio	29.3	11.0	2.3	-	46.5	6.6	73.5	2.5	0.1	-	96.1	1.4	305.5	5.2
Subtotal	284.0	125.0	12.0	3.9	242.9	31.2	279.1	22.0	4.2	2.9	290.7	4.6	894.4	19.4
TENNESSEE VALLEY														
Washington, D.C.	0.2	.2	-	-	-	-	-	-	-	-	-	-	-	-
Missouri	21.0	5.0	0.9	.5	2.9	-	24.8	1.5	.5	-	54.2	1.1	16.2	.4
Arkansas	9.3	3.4	1.0	.7	34.9	3.1	55.4	-	0.1	-	16.8	.2	12.4	-
Kentucky	11.9	2.7	0.4	.2	7.5	-	30.6	2.3	(D)	-	9.9	.1	54.8	-
Tennessee	17.3	5.3	1.4	1.0	27.1	1.9	109.2	12.8	0.6	.3	26.2	.1	15.3	.5
W. Virginia	1.0	.5	-	-	-	-	85.2	-	-	-	23.3	.1	47.8	.2
Virginia	11.5	3.5	1.9	1.6	42.1	5.2	59.7	15.1	-	-	15.2	.6	7.3	1.1
N. Carolina	9.7	2.4	4.4	3.9	47.4	3.7	39.4	7.9	0.3	-	21.5	1.0	5.7	.1
Maryland	11.1	8.3	0.2	.1	12.0	-	16.7	3.7	0.2	-	18.1	.2	29.8	-
Deleware	1.9	.6	-	-	1.2	3.0	-	-	-	-	-	-	2.0	-
Subtotal	94.9	27.9	10.2	8.0	175.1	13.9	443.6	46.3	1.7	.3	185.2	3.4	188.8	2.3
GULF COAST														
Louisiana	22.	3.1	-	-	69.2	10.4	460.4	6.3	-	-	17.1	.3	60.4	-
Mississippi	5.8	2.4	0.8	-	25.5	-	21.6	.6	(Z)	-	16.7	.1	-	-
Alabama	6.4	2.8	0.5	.3	72.6	10.3	48.1	6.2	-	-	30.1	.4	66.2	2.3
Georgia	14.2	4.4	0.5	.3	72.1	7.5	23.9	.9	0.1	-	28.8	.4	6.8	-
Florida	22.6	9.9	0.4	.2	57.6	4.0	52.6	-	(Z)	-	19.4	.4	3.3	-
S. Carolina	2.7	.5	36.7	-	28.6	4.6	44.1	11.0	-	-	20.9	.8	7.7	-
Subtotal	73.9	23.1	38.9	.8	325.6	36.8	650.7	25.0	0.1	0	133.0	1.7	144.4	2.3

Table J-1. Distribution of Energy Used by 2-Digit SIC Code and State (10^{12} Btu) (Concluded)

REGION	SIC 20 Total Thermal	SIC 20 200°F Thermal	SIC 25 Total Thermal	SIC 25 200°F Thermal	SIC 26 Total Thermal	SIC 26 200°F Thermal	SIC 28 Total Thermal	SIC 28 200°F Thermal	SIC 31 Total Thermal	SIC 31 200°F Thermal	SIC 32 Total Thermal	SIC 32 200°F Thermal	SIC 33 Total Thermal	SIC 33 200°F Thermal
ATLANTIC NORTHEAST														
Pennsylvania	31.9	11.0	2.0	0.8	48.8	6.6	53.2	9.6	1.8	1.4	96.2	1.1	374.4	2.8
New Jersey	20.5	4.9	0.8	0.3	24.3	2.7	78.4	7.0	0.5	0.3	40.4	0.3	15.6	-
New York	29.8	10.3	2.1	0.9	39.5	5.2	56.7	1.6	(D)	1.5	37.9	0.5	53.5	0.9
Connecticut	2.4	0.4	0.4	0.2	6.6	0.9	9.2	0.5	-	-	4.2	0.1	9.3	0.3
Rhode Island	1.6	-	-	-	1.4	-	1.1	-	-	-	2.4	-	2.5	-
Massachusetts	7.5	2.3	1.1	0.9	21.6	2.0	10.9	3.0	1.9	1.2	7.5	.2	2.7	0.2
New Hampshire	1.1	0.3	0.1	-	11.5	1.7	0.5	-	1.0	0.8	1.3	-	-	-
Vermont	1.2	0.6	0.2	-	2.7	-	-	-	-	-	0.9	-	-	-
Maine	4.3	1.5	0.1	-	55.8	2.2	0	-	1.3	0.8	2.9	-	0	9.5
Subtotal	100.3	31.3	4.9	3.1	212.2	26.3	210.0	21.7	6.5	6.0	193.5	2.2	458.0	4.2
HAWAII	5.9	0.6	-	-	-	-	-	-	-	-	1.7	-	-	-
ALASKA	1.4	-	-	-	-	-	-	-	-	-	-	-	-	-
PUERTO RICO*	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GRAND TOTAL**	815.0	284.0	69.3	17.7	1110.0	120.0	2460.0	148.0	12.5	3.2	1120.0	16.0	1900.0	31.0

*No information given on energy consumption.

**Numbers may not add due to rounding.

(D) Notation would reveal proprietary information.

(Z) Statistically insignificant.

J.2 INDUSTRIAL PROCESS HEAT SECTOR:
DISTRIBUTION OF STATE ENERGY USE BY SMSA/NON-SMSA

Table J-2. Distribution of State Energy Use by SMSA/Non-SMSA

REGION	TOTAL THERMAL 10^{12} Btus	TOTAL THERMAL 200°F 10^{12} Btus	SMSA THERMAL 200°F 10^{12} Btus	NON-SMSA THERMAL 200°F 10^{12} Btus
PACIFIC NORTHWEST				
Washington	143.3	6.4	2.3	4.1
Oregon	32.9	6.5	3.8	2.7
Idaho	45.8	8.5	0.1	8.4
Subtotal	222.0	21.4	6.2	15.2
SALT LAKE				
N. California	284.7	18.0	14.3	3.7
Colorado	61.7	2.6	1.0	1.6
Utah	48.4	1.1	0.4	0.7
Nevada	14.4	0.3	0.2	0.1
Subtotal	405.2	22.0	15.9	6.1
SOUTHWEST				
Arizona	54.8	0.6	0.5	0.1
N. Mexico	19.4	0.5	0.1	0.4
S. California	331.2	26.6	20.0	6.6
Subtotal	405.5	27.7	20.6	7.1
RED RIVER				
Texas	1676.7	43.4	24.1	19.3
Kansas	110.7	4.1	0.8	3.3
Oklahoma	122.7	1.9	1.8	.1
Subtotal	1910.1	49.4	26.7	22.7
BLACK HILLS				
Montana	34.7	3.6	1.8	1.8
Wyoming	21.9	0	0	0
N. Dakota	11.3	0.5	-	0.5
S. Dakota	4.7	2.1	1.0	1.1
Nebraska	49.5	7.5	0.7	6.8
Subtotal	122.1	13.7	3.5	10.2
GREAT LAKES				
Minnesota	120.2	17.8	5.1	12.6
Iowa	152.4	24.2	1.5	22.7
Wisconsin	207.2	35.5	7.5	28.0
Illinois	522.1	54.3	24.1	30.2
Michigan	476.4	30.2	12.6	17.6
Indiana	448.6	15.3	9.0	6.3
Ohio	731.4	31.7	20.9	10.8
Subtotal	2658.3	209.0	80.8	128.2

Table J-2. (Cont'd)

REGION	TOTAL THERMAL 10^{12} Btus	TOTAL THERMAL 200°F 10^{12} Btus	SMSA THERMAL 200°F 10^{12} Btus	NON-SMSA THERMAL 200°F 10^{12} Btus
TENNESSEE VALLEY				
Missouri	153.8	8.5	7.0	1.5
Arkansas	154.5	7.4	1.7	5.7
Kentucky	152.7	5.3	3.2	2.1
Tennessee	230.6	21.9	7.1	14.8
W. Virginia	171.0	0.8	0.3	0.5
Virginia	185.1	27.1	1.7	25.4
N. Carolina	216.7	19.0	7.0	12.0
Maryland	107.9	8.3	5.7	2.6
Deleware	38.9	3.6	4.4*	0.4
Washington, D. C.	0.2	0.2	0.2	-
Subtotal	1411.4	102.1	38.3	65.0
GULF COAST				
Louisiana	789.3	20.1	1.6	18.5
Mississippi	130.8	3.1	0.6	2.5
Alabama	255.4	22.3	5.0	17.3
Georgia	201.6	13.5	3.8	9.7
Florida	159.6	14.8	9.3*	5.5
S. Carolina	174.1	16.2	2.5	13.7
Subtotal	1710.8	90.0	22.8	67.2
ATLANTIC NORTHEAST				
Pennsylvania	751.4	33.3	26.9	6.4
N. Jersey	265.4	15.5	9.1	6.4
N. York	343.3	20.9	14.5	6.4
Connecticut	67.5	2.4	1.2	1.2
Rhode Island	18.3	0	0	0
Massachusetts	104.3	9.8	5.7	4.1
Vermont	8.1	0.6	0	0.6
New Hampshire	21.4	2.8	0.3	2.5
Maine	74.5	9.5	0.5	9.0
Subtotal	1654.2	94.8	58.2	36.6
ALASKA	8.5	0	0	0
HAWAII	8.1	0.6	0.2	0.4
PUERTO RICO	0	0	0	0
GRAND TOTAL	10,520.1	631.9	273.7	358.7

J.3 INDUSTRIAL PROCESS HEAT SECTOR: THERMAL REQUIREMENTS LESS THAN 200°F IN INDUSTRIAL PROCESSES

Table J-3. Energy Use in Industrial Process

SIC CATEGORY	TEMPEATURE REQUIREMENT 200°F	% THERMAL 200°F TO TOTAL THERMAL
SIC 20 FOOD PROCESSING		
201 Meat Products		97
2011 Meat Processing (scalding, clean-up)	140	
2016 Poultry Dressing (scalding)	140	
202 Dairy Products		75
2022 Natural Cheese (whey condensing)	160-200	
2023 Condensed & Evaporated Milk (evaporation)	160	
2026 Fluid Milk (pasteurization)	162-170	
203 Preserved Fruits & Vegetables		57
2032 Canned Specialties (1. precook	180-212	
2. summer blend	170-212	
3. sauce heating)	190	
2033 Canned Fruits & Vegetables (drying)	165-185	
2037 Frozen fruits & Vegetables (1. Citrus juice preparation	190	
2. Blanding)	180-200	
204 Grain Mill Products		34
2046 Wet Corn Milling (1. starch dryer	120	
2. steep water heater	120	
3. sugar dryer)	120	
205 Bakery	100	11
2051 Proofing		
206 Sugar		13
2062 Crystalline Sugar		
2063 Beet Sugar (Water heating)	140-185	
207 Fats & Oils		14
2075 Soybean Oil Mills (Bean drying)	160	

Table J-3. (Cont'd)

SIC CATEGORY	TEMPEATURE REQUIREMENT 200°F	% THERMAL 200°F TO TOTAL THERMAL
2079 Shortening & Cooking Oil		
(1. oil heater	120-180	
2. wash water)	160-180	
208 Beverages		10
2086 Soft Drinks		
(1. bulk container washing	170	
2. returnable bottle washing	170	
3. non-returnable bottle warming	75-85	
4. can warming)	75-85	
SIC 25 FURNITURE AND FIXTURES		
251 Household Furniture		100
2511 Wooden Furniture		
(1. kiln	150	
2. make-up)	70	
2512 Upholstered Furniture		
(1. kiln	150	
2. make-up)	70	
SIC 26 PAPER & ALLIED PRODUCTS	120	16
2611 Pulp Mills		
2621 Paper Mills		
2631 Paperboard Mills (pulp refining)	120	
SIC 28 CHEMICALS & ALLIED PRODUCTS		
282 Plastic Materials, Synthetics		41
2821 Plastic Materials (wash water)	190-200	
2822 Synthetic Rubber		
(1. latex crumb dryer	150-200	
2. latex crumb recovery)	120-140	
283 Pharmaceutical Preparation	140	7

Table J-3. (Concluded)

SIC CATEGORY	TEMPEATURE REQUIREMENT 200^oF	% THERMAL 200^oF TO TOTAL THERMAL
284 Soaps, Cleaners, Toilet Goods		75
2841 Soaps & Detergents		
(1. soap manufacturing	180	
2. detergent low-temperature process)	180	
SIC 31 LEATHER, LEATHER PRODUCTS		
3111 Leather Tanning & Finishing		100
(1. bating	90	
2. chrome tanning	80-130	
3. retan, drying	120-140	
4. drying	110	
SIC 32 STONE, CLAY & GLASS PRODUCTS		
327 Concrete, Gypsum & Plaster		7
2271 Concrete Block (low-pressure curing)	165	
2273 Ready Mix Concrete (hot water)	120-190	
SIC 33 PRIMARY METALS INDUSTRIES		
332 Iron & Steel Foundaries		26
3321 Ferrous casting, iron foundaries		
3322 Ferrous casting, malleable foundaries		
3323 Ferrous casting, steel foundaries (pickling)	110-212	

APPENDIX K

AGRICULTURAL ENERGY CONSUMPTION DATA

Table K-1. Agricultural Energy Consumption, Crops Only (Total)

Regions/States	Energy Use and Fuel Types							
	Gasoline, 10^3 gal	Diesel, 10^3 gal	LP Gas, 10^3 gal	Fuel Oil, 10^3 gal	Natural Gas, 10^6 ft^3	Coal, ton	Electricity, 10^6 kWh	Total, 10^9 Btu
Pacific Northwest Region	79268	95239	8790	15407	1436		7009	79800
Washington	32108	31223	2962	7954	316		3790	35183
Oregon	20441	23204	1985	7453	231		1609	18905
Idaho	26719	40812	3843		889		1610	25712
Salt Lake Region	101508	117593	11899	24097	7774		3281	77613
Northern California	52450	67982	4039	23406	2085		2314	46651
Northern Nevada	1817	4222	594		52		193	1797
Utah	9098	11517	887		280		341	5711
Colorado	34510	33874	6379	691	5357		436	23459
Southwest Region	83393	105921	22723	29369	32108		5015	10882
Southern California	52450	67982	4039	23406	2085		2314	46651
Southern Nevada	1817	4222	594		52		193	1797
Arizona	14199	15221	464	5963	14675		2098	34310
New Mexico	14927	18497	17626		15296		412	26064
Black Hills Region	361039	415572	186279	18	13479		1855	220118
Montana	51122	29345	4355		334		231	22629
Wyoming	10924	10847	1609		122		218	6170
North Dakota	113934	79458	4348		111		123	39031
South Dakota	68438	80843	29221	6	150		145	31480
Nebraska	116621	215079	146746	12	12762		1138	120808

Table K-1. (Cont'd)

Regions/States	Energy Use and Fuel Types							
	Gasoline, 10^3 gal	Diesel, 10^3 gal	LP Gas, 10^3 gal	Fuel Oil, 10^3 gal	Natural Gas, 10^6 ft^3	Coal, ton	Electricity, 10^6 kWh	Total, 10^9 Btu
Red River Region	363201	349354	118026	10316	94115		2013	324195
Kansas	129060	112053	42759		21845		290	91977
Oklahoma	64935	61445	18626		6262		168	45419
Texas	169206	175856	56641	10316	66008		1555	186800
Great Lakes Region	1151933	499993	454391	10254	3291		1023	502918
Minnesota	207264	92490	62215	144	549		211	84224
Iowa	272385	118158	115339	127	366		177	115355
Wisconsin	138379	39418	34663	46	410		130	43626
Illinois	239000	108496	127283	75	321		213	113839
Michigan	72480	44871	17550	6364	383		86	33712
Indiana	122946	53979	65806	21	148		112	64139
Ohio	99479	42581	31535	3477	1114		94	48023
Tennessee Valley Region	346073	292428	232610	57579	4458		517	222849
Missouri	110327	50785	33082	182	453		102	53916
Arkansas	55528	89571	29842		2510		142	41967
Kentucky	39873	26946	13014	1345	236		31	22414
Tennessee	33065	31386	5808	500	312		31	20826
West Virginia	6493	2561	1050	740			4	3463
Virginia	23269	23146	22957	7918	61		33	18880
North Carolina	49541	52415	122144	46822	490		158	50160
Maryland	19997	10686	4051	72	96		12	8140
Delaware	7980	4932	662				4	3083

Table K-1. (Cont'd)

Regions/States	Energy Use and Fuel Types							
	Gasoline, 10^3 gal	Diesel, 10^3 gal	LP Gas, 10^3 gal	Fuel Oil, 10^3 gal	Natural Gas, 10^6 ft^3	Coal, ton	Electricity, 10^6 kWh	Total, 10^9 Btu
Gulf Coast Region	249081	331053	93132	141129	2705		572	188780
Louisiana	41163	64230	7817		1909		63	28367
Alabama	24719	31911	4199	426	65		23	18409
Mississippi	43449	65190	9465	503	105		56	3306
Georgia	48724	55916	31538	9466	520		69	353
South Carolina	28326	28170	23220	9241	66		53	18776
Florida	67200	84636	16893	121493	40		308	64821
Atlantic Northeast Region	142153	72920	20750	6944	435		77	58564
Pennsylvania	55852	30212	9982	2223	435		33	23602
New Jersey	13473	6647	1116				9	4696
New York	56830	27929	6656	4159			25	22492
Vermont	4696	1437	792				3	2260
New Hampshire	1042	535	151				1	551
Massachusetts	2641	1753	366	562			2	1277
Connecticut	2119	1303	1316				1	1098
Rhode Island	329	150	28					156
Maine	5171	2954	343				3	2432
Alaska Region	212	2	41					59
Hawaii Region	7055	6473	18				698	6214
Puerto Rico Region								
National Total	2881276	2286539	1148657	295112	159500		22060	1789930

Table K-2. Agricultural Energy Consumption, Livestock Only (Total)

Regions/States	Energy Use and Fuel Types							
	Gasoline, 10^3 gal	Diesel, 10^3 gal	LP Gas, 10^3 gal	Fuel Oil, 10^3 gal	Natural Gas, 10^6 ft^3	Coal, ton	Electricity, 10^6 kWh	Total, 10^9 Btu
Pacific Northwest Region	36562	1450	11780		6	24	374	7175
Washington	10892	519	4335		2		158	2388
Oregon	10292	466	4419		1		89	2086
Idaho	15378	465	2926		3	24	127	2701
Salt Lake Region	49926	27418	13111	851	899	2093	489	14106
Northern California	26235	25111	8432	851	777		354	8337
Northern Nevada	2332	43	40				8	363
Utah	5733	300	2127		42	1984	50	1225
Colorado	15626	11964	2152		80	109	77	418
Southwest Region	50469	17276	10186	851	779	19	512	1237
Southern California	26235	25111	8432	851	777		354	8331
Southern Nevada	2332	43	40				8	363
Arizona	9982	1309	837		1	4	100	1852
New Mexico	11920	813	516		1	15	50	1824
Black Hills Region	69631	71577	7678	25	2	236	343	20635
Montana	7416	74	1506			41	29	1182
Wyoming	6652	3402	149			10	9	1353
North Dakota	10154	18946	1445	3		45	62	4271
South Dakota	20584	23547	2105	9		140	101	6418
Nebraska	24825	25608	2473	1[illegible]	2		142	7411

Table K-2. (Cont'd)

Regions/States	Energy Use and Fuel Types							
	Gasoline, 10^3 gal	Diesel, 10^3 gal	LP Gas, 10^3 gal	Fuel Oil, 10^3 gal	Natural Gas, 10^6 ft^3	Coal, ton	Electricity, 10^6 kWh	Total, 10^9 Btu
Red River Region	153905	30596	15772	15	1110		766	28804
Kansas	19922	24210	2243	15	2		112	6480
Oklahoma	38998	581	2841		270		117	5908
Texas	94985	5805	10688		838		537	16416
Great Lakes Region	215232	116068	98640	584	59	2573	4126	66821
Minnesota	36896	16999	27694	71		314	760	12234
Iowa	55889	46423	28051	59		249	1032	19688
Wisconsin	39421	5679	11915	124			996	10272
Illinois	29529	21139	11455	47	4	391	481	9436
Michigan	12929	3758	4237	41			270	3472
Indiana	20954	13020	8123	147	58	990	286	6297
Ohio	19614	9050	7165	95	1	629	291	5422
Tennessee Valley Region	119069	55857	93323	1925	568	15090	1207	40565
Missouri	29431	24982	13015	72			362	9660
Arkansas	15774	5047	27558		376		168	6265
Kentucky	19491	7503	2898	196	2	568	6	4447
Tennessee	17379	6431	4860	21	6	916	134	4024
West Virginia	2636	1720	1767	93	7	1423	32	904
Virginia	10059	4309	6678	460	35	4898	133	3177
North Carolina	16519	4253	20664	346	142	7285	222	5767
Maryland	5411	840	9465	419			107	2117
Delaware	2369	772	6418	318			318	1204

Table K-2. (Cont'd)

Regions/States	Energy Use and Fuel Types							
	Gasoline, 10^3 gal	Diesel, 10^3 gal	LP Gas, 10^3 gal	Fuel Oil, 10^3 gal	Natural Gas, 10^6 ft^3	Coal, ton	Electricity, 10^6 kWh	Total, 10^9 Btu
Gulf Coast Region	71515	27335	64247	18	913	7590	790	22725
Louisiana	6840	3364	2720		342		75	2200
Alabama	13870	5651	19812		138	7276	161	5292
Mississippi	13230	5686	10327		228		123	4090
Georgia	19949	6708	23340		198		247	6701
South Carolina	6021	2062	2943	18	7	314	64	1557
Florida	11605	3864	5105				120	2885
Atlantic Northeast Region	49068	4773	17971	4695	284	5100	1226	13775
Pennsylvania	18178	2691	8699	339		3780	426	5075
New Jersey	1605	246	642	58	1		41	444
New York	18122	1073	4938	132	283	1320	501	4945
Vermont	3859	99	1530	27			84	931
New Hampshire	808	56	285	90			20	216
Massachusetts	1579	141	619	159			33	410
Connecticut	1930	343	688	139			42	516
Rhode Island	178	19	69	15			4	46
Maine	2809	105	501	3736			75	1192
Alaska Region	70	40	23	4			1	21
Hawaii Region	1921	20	155	40			10	297
Puerto Rico Region								
National Total	817365	352416	332885	8817	4625	32725	10028	224291

Table K-3. Agricultural Energy Consumption,Crop Drying (Total)

Regions/States	Energy Use and Fuel Types							
	Gasoline, 10^3 gal	Diesel, 10^3 gal	LP Gas, 10^3 gal	Fuel Oil, 10^3 gal	Natural Gas, 10^6 ft^3	Coal, ton	Electricity, 10^6 kWh	Total, 10^9 Btu
Pacific Northwest Region					1030		13	1126
Washington					316		4	345
Oregon					231		3	253
Idaho					483		6	528
Salt Lake Region			3264		2409		20	2906
Northern California			1205		1502		11	1730
Northern Nevada					52		1	57
Utah					189		2	206
Colorado			2059		666		6	914
Southwest Region			1304		1938		17	22
Southern California			1205		1502		11	173
Southern Nevada					52		1	57
Arizona			57		251		3	279
New Mexico			42		133		2	149
Black Hills Region			59476	18	7182		133	13648
Montana					326		4	356
Wyoming								
North Dakota			36		111		2	125
South Dakota			21561	6	150		19	2272
Nebraska			37879	12	6595		108	10895
Red River Region			20863		4819		69	7225
Kansas			16603		2462		47	8321
Oklahoma			142		322		4	365
Texas			4118		2035		18	2589

Table K-3. (Cont'd)

Regions/States	Energy Use and Fuel Types							
	Gasoline, 10^3 gal	Diesel, 10^3 gal	LP Gas, 10^3 gal	Fuel Oil, 10^3 gal	Natural Gas, 10^6 ft^3	Coal, ton	Electricity, 10^6 kWh	Total, 10^9 Btu
Great Lakes Region			343795	3084	3288		325	37654
Minnesota			40966	144	366		39	4428
Iowa			92192	127	549		82	9634
Wisconsin			15286	46	410		17	1946
Illinois			107693	75	321		92	10894
Michigan			10788	33	383		14	1478
Indiana			54638	21	145		46	5504
Ohio			22832	2638	1114		35	3770
Tennessee Valley Region			172884	54519	3907		187	28799
Missouri			20899	182	450		26	2574
Arkansas			4326		2263		19	2851
Kentucky			7640	1345	236		6	1184
Tennessee			1758	500	311		6	583
West Virginia			4					
Virginia			20208	6635	61		16	2969
North Carolina			115847	45785	490		111	18308
Maryland			2202	72	96		3	330
Delaware								

Table K-3. (Cont'd)

Regions/States	Energy Use and Fuel Types							
	Gasoline, 10^3 gal	Diesel, 10^3 gal	LP Gas, 10^3 gal	Fuel Oil, 10^3 gal	Natural Gas, 10^6 ft^3	Coal, ton	Electricity, 10^6 kWh	Total, 10^9 Btu
Gulf Coast Region			57707	18803	2176		86	10693
Louisiana			3034		1381		12	1779
Alabama			2126	426	64		4	343
Mississippi			777	503	105		4	267
Georgia			25979	8232	520		37	4294
South Carolina			20643	7958	66		22	3221
Florida			5148	1684	40		7	787
Atlantic Northeast Region			5148	143	435		9	995
Pennsylvania			4073	143	435		9	893
New Jersey								
New York								
Vermont								
New Hampshire								
Massachusetts								102
Connecticut			1075					
Rhode Island								
Maine								
Alaska Region								
Hawaii Region								
Puerto Rico Region								
National Total			664440	76564	27182		858	105261

Table K-4. Agricultural Energy Consumption, Irrigation

Regions/States	Energy Use and Fuel Types							
	Gasoline, 10^3 gal	Diesel, 10^3 gal	LP Gas, 10^3 gal	Fuel Oil, 10^3 gal	Natural Gas, 10^6 ft^3	Coal, ton	Electricity, 10^6 kWh	Total, 10^9 Btu
Pacific Northwest Region	3678	2705	2165		406		6927	25109
Washington							3758	12825
Oregon		1320					1588	5604
Idaho	3678	1385	2165		406		1581	6680
Salt Lake Region	4033	10718	2608		5365		3179	18738
Northern California		35			582		2257	8319
Northern Nevada	252	4025	315				191	1276
Utah	3480	5482	455		91		333	2478
Colorado	301	1176	1839		4692		399	6666
Southwest Region	8076	13441	17430		30170		4933	53060
Southern California		35			582		2257	8319
Southern Nevada	252	4025	315				191	1276
Arizona					14425		2081	22248
New Mexico	7824	9381	17115		15163		404	21217
Black Hills Region	6738	90708	106225		6297		1387	34981
Montana	1203	2104	281		8		178	1089
Wyoming	262	1617	665		122		209	1163
North Dakota	157	333	65				19	138
South Dakota	701	2518	4083				44	979
Nebraska	4415	84136	101131		6167		937	31612

Table K-4. (Cont'd)

Regions/States	Energy Use and Fuel Types							
	Gasoline, 10^3 gal	Diesel, 10^3 gal	LP Gas, 10^3 gal	Fuel Oil, 10^3 gal	Natural Gas, 10^6 ft^3	Coal, ton	Electricity, 10^6 kWh	Total, 10^9 Btu
Red River Region	11172	17923	67593		89296		1648	109714
Kansas	1938	8021	17389		19383		133	23825
Oklahoma	2228	3921	13387		5940		108	8705
Texas	7006	5981	36817		63973		1407	77184
Great Lakes Region	3629	3907	2054		3		142	1685
Minnesota	403	1382	576				31	404
Iowa	508	355	79				2	129
Wisconsin	414	992					64	410
Illinois	986	289	528				2	222
Michigan	242	581					38	240
Indiana	695	194	752		3		2	194
Ohio	381	114	119				3	86
Tennessee Valley Region	13774	5044	23715		252		115	5340
Missouri	801	465	1442		3		6	327
Arkansas	10868	3630	21735		284		84	4480
Kentucky	332	47						48
Tennessee	202	121	49		1		1	51
West Virginia	53	12						9
Virginia	669	141	74				1	113
North Carolina	122	97					21	101
Maryland	269	287	224				1	98
Delaware	458	244	191				1	113

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Table K-4. (Cont'd)

Regions/States	Energy Use and Fuel Types							
	Gasoline, 10^3 gal	Diesel, 10^3 gal	LP Gas, 10^3 gal	Fuel Oil, 10^3 gal	Natural Gas, 10^6 ft^3	Coal, ton	Electricity, 10^6 kWh	Total, 10^9 Btu
Gulf Coast Region	12830	31362	14077		529		228	8662
Louisiana	4227	6757	1321		528		31	2259
Alabama	221	176	29		1		1	59
Mississippi	1213	5818	1516				24	[illegible]
Georgia	3251	2298	1418				3	73
South Carolina		314					15	96
Florida	3918	15999	9793				154	4184
Atlantic Northeast Region	5886	1332	464				8	996
Pennsylvania	317	61	6					50
New Jersey	4163	713	372				6	675
New York	706	451					1	156
Vermont	21	8						4
New Hampshire	64	24						12
Massachusetts	392		78				1	59
Connecticut	102	34	4					18
Rhode Island	31	12						6
Maine	90	29	4					16
Alaska Region	221	176	29		1		1	59
Hawaii Region	723						696	2465
Puerto Rico Region								
National Total	70551	177140	236328		132317		19263	260809

Table K-5. (Cont'd)

Regions/States	Energy Use and Fuel Types							
	Gasoline, 10^3 gal	Diesel, 10^3 gal	LP Gas, 10^3 gal	Fuel Oil, 10^3 gal	Natural Gas, 10^6 ft^3	Coal, ton	Electricity, 10^6 kWh	Total, 10^9 Btu
Red River Region			7127				27	769
Kansas			1745				2	175
Oklahoma			1406				6	153
Texas			3976				19	441
Great Lakes Region			61273				637	7133
Minnesota			8420				153	1321
Iowa			22936				89	2483
Wisconsin			8074				249	747
Illinois			10421				46	1145
Michigan			2937				44	429
Indiana			4078				26	478
Ohio			4407				32	530
Tennessee Valley Region			19210				96	2150
Missouri			8856				23	917
Arkansas			971				4	108
Kentucky			2145				29	302
Tennessee			1349				6	244
West Virginia			343				4	45
Virginia			1351				12	170
North Carolina			1823				10	206
Maryland			1227				7	142
Delaware			145				1	16

Table K-5. Agricultural Energy Consumption, Livestock Shelter Space and Water Heating

Regions/States	Energy Use and Fuel Types							
	Gasoline, 10^3 gal	Diesel, 10^3 gal	LP Gas, 10^3 gal	Fuel Oil, 10^3 gal	Natural Gas, 10^6 ft^3	Coal, ton	Electricity, 10^6 kWh	Total, 10^9 Btu
Pacific Northwest Region			3840		5		37	496
Washington			1405		2		15	187
Oregon			952				11	128
Idaho			1483		3		11	181
Salt Lake Region			6440				31	704
Northern California			4755				19	516
Northern Nevada			93				2	14
Utah			688				6	84
Colorado			905				5	91
Southwest Region			6060				23	223
Southern California			4755				19	516
Southern Nevada			93				2	14
Arizona			792				1	80
New Mexico			420				1	43
Black Hills Region			3910				42	512
Montana			229				6	39
Wyoming			128					13
North Dakota			768				15	123
South Dakota			994				18	156
Nebraska			1791				3	180

Table K-5. (Cont'd)

Regions/States	Energy Use and Fuel Types							
	Gasoline, 10^3 gal	Diesel, 10^3 gal	LP Gas, 10^3 gal	Fuel Oil, 10^3 gal	Natural Gas, 10^6 ft^3	Coal, ton	Electricity, 10^6 kWh	Total, 10^9 Btu
Gulf Coast Region			8002				37	929
Louisiana			1317				6	147
Alabama			684				5	126
Mississippi			1359				7	151
Georgia			1622				9	185
South Carolina			657				4	75
Florida			2363				6	245
Atlantic Northeast Region		1	10206				220	1723
Pennsylvania		1	3171				82	579
New Jersey			325				4	46
New York			3863				107	733
Vermont			1507				11	181
New Hampshire			207				3	28
Massachusetts			462				3	55
Connecticut			340				4	47
Rhode Island			51					6
Maine			280				6	48
Alaska Region			23					2
Hawaii Region			155				1	17
Puerto Rico Region								
National Total		1	126690		10		1149	14658

Table K-6. Agricultural Energy Consumption, Livestock Brooding

Regions/States	Energy Use and Fuel Types							
	Gasoline, 10^3 gal	Diesel, 10^3 gal	LP Gas, 10^3 gal	Fuel Oil, 10^3 gal	Natural Gas, 10^6 ft^3	Coal, ton	Electricity, 10^6 kWh	Total, 10^9 Btu
Pacific Northwest Region			2875		1	24		274
Washington			1444					137
Oregon			1324					126
Idaho			107		1	24		11
Salt Lake Region			3690	822	785	2093		1343
Northern California			1514	822	672			964
Northern Nevada			2					
Utah			981		37	1984		183
Colorado			1194		76	109		196
Southwest Region			1611	822	673	19		975
Southern California			1514	822	672			964
Southern Nevada			2					
Arizona			25			4		3
New Mexico			70		1	15		8
Black Hills Region			8545	25	2	236		254
Montana			180			41		18
Wyoming			19			10		2
North Dakota			664	3		45		65
South Dakota			1056	9		140		105
Nebraska			626	13	2			64

Table K-6. (Cont'd)

Regions/States	Energy Use and Fuel Types							
	Gasoline, 10^3 gal	Diesel, 10^3 gal	LP Gas, 10^3 gal	Fuel Oil, 10^3 gal	Natural Gas, 10^6 ft^3	Coal, ton	Electricity, 10^6 kWh	Total, 10^9 Btu
Red River Region			8197	15	1014			1846
Kansas			455	15	2			47
Oklahoma			1378		250			394
Texas			6364		762			1405
Great Lakes Region			36351	539	62	2573		3661
Minnesota			19069	64		314		1829
Iowa			4966	52		249		486
Wisconsin			3747	119				373
Illinois			932	42	3	391		108
Michigan			1192	36				118
Indiana			3858	139	58	990		472
Ohio			2587	87	1	629		275
Tennessee Valley Region			72107	1690	536	15090		8042
Missouri			4054	68				395
Arkansas			26006		356			2844
Kentucky			709	6	1	568		85
Tennessee			2420	21	6	916		263
West Virginia			1399	91	7	1423		190
Virginia			4771	449	34	4898		679
North Carolina			18373	325	132	7285		2119
Maryland			8156	419				833
Delaware			6219	311				634

Table K-6. (Cont'd)

Regions/States	Energy Use and Fuel Types							
	Gasoline, 10^3 gal	Diesel, 10^3 gal	LP Gas, 10^3 gal	Fuel Oil, 10^3 gal	Natural Gas, 10^6 ft^3	Coal, ton	Electricity, 10^6 kWh	Total, 10^9 Btu
Gulf Coast Region			53427	18	826	7590		6143
Louisiana			1330		306			448
Alabama			18206		128	7276		2054
Mississippi			8687		208			1044
Georgia			20723		177			2154
South Carolina			2132	18	7	314		220
Florida			2349					223
Atlantic Northeast Region			7318	4187	281	5100		1709
Pennsylvania			5362	207		3780		637
New Jersey			279	17	1			30
New York			989	54	280	1320		430
Vermont			17	20				4
New Hampshire			66	75				17
Massachusetts			134	135				32
Connecticut			305	95				42
Rhode Island			15	12				3
Maine			151	3572				514
Alaska Region				3				
Hawaii Region				9				1
Puerto Rico Region								
National Total			188120	8129	4181	32725		24248

Table K-7. Agricultural Energy Consumption, Livestock Waste Disposal

Regions/States	Energy Use and Fuel Types							
	Gasoline, 10^3 gal	Diesel, 10^3 gal	LP Gas, 10^3 gal	Fuel Oil, 10^3 gal	Natural Gas, 10^6 ft^3	Coal, ton	Electricity, 10^6 kWh	Total, 10^9 Btu
Pacific Northwest Region	4265	772	253				12	704
Washington	1713	294	154				7	293
Oregon	976	157	83				2	158
Idaho	1576	321	16				3	253
Salt Lake Region	6355	1821	288	29	112		2	1205
Northern California	4765	1594	208	29	103		1	952
Northern Nevada	83	6	1					11
Utah	731	68	26		5		1	114
Colorado	777	153	53		4			128
Southwest Region	6362	1782	255	29	103		1	1183
Southern California	4765	1594	208	29	103		1	952
Southern Nevada	83	6	1					11
Arizona	924	135	20					137
New Mexico	590	47	26					83
Black Hills Region	3780	1161	143				5	669
Montana	224	13	17					33
Wyoming	134	11	2					19
North Dakota	828	13	13				2	113
South Dakota	1162	418	55				2	217
Nebraska	1432	706	56				1	287

Table K-7. (Cont'd)

Regions/States	Energy Use and Fuel Types							
	Gasoline, 10^3 gal	Diesel, 10^3 gal	LP Gas, 10^3 gal	Fuel Oil, 10^3 gal	Natural Gas, 10^6 ft^3	Coal, ton	Electricity, 10^6 kWh	Total, 10^9 Btu
Red River Region	10668	1799	448		95			1730
Kansas	1355	832	43					291
Oklahoma	2293	81	57		19			324
Texas	7020	886	348		76			1115
Great Lakes Region	27201	25980	1016	45	1		47	7306
Minnesota	5360	4332	205	7			6	1318
Iowa	3042	10721	149	7			7	1920
Wisconsin	8654	1219	94	5			12	1303
Illinois	1885	4606	102	5			4	906
Michigan	2910	855	108	5			9	524
Indiana	2017	2529	187	8	1		4	638
Ohio	3333	1718	171	8			7	697
Tennessee Valley Region	15767	7928	1537	45	32		24	3345
Missouri	2974	2550	105	4			3	749
Arkansas	2412	278	581		20		1	421
Kentucky	1938	1592	44				5	486
Tennessee	2063	1048	91				3	422
West Virginia	399	169	25	2			1	79
Virginia	1698	866	87	11	2		5	361
North Carolina	2580	1067	468	21	10		3	540
Maryland	1345	143	82				3	205
Delaware	358	215	54	7				82

Table K-7. (Cont'd)

Regions/States	Energy Use and Fuel Types							
	Gasoline, 10^3 gal	Diesel, 10^3 gal	LP Gas, 10^3 gal	Fuel Oil, 10^3 gal	Natural Gas, 10^6 ft^3	Coal, ton	Electricity, 10^6 kWh	Total, 10^9 Btu
Gulf Coast Region	10559	2592	2368		89		7	2025
Louisiana	1278	98	73		36			219
Alabama	1877	607	472		10		1	379
Mississippi	1745	301	281		20		2	314
Georgia	2714	1069	995		22		3	616
South Carolina	752	330	154		1		1	159
Florida	2193	187	393					338
Atlantic Northeast Region	12811	809	447	508	3		24	1916
Pennsylvania	4330	502	166	132			8	675
New Jersey	400	45	38	41			1	69
New York	4819	121	86	78	3		12	681
Vermont	1256	9	6	7			2	168
New Hampshire	255	7	12	15				37
Massachusetts	449	25	23	24			1	67
Connecticut	500	88	43	44				86
Rhode Island	48	3	3	3				7
Maine	754	9	70	164				126
Alaska Region	18			1				
Hawaii Region	251	2		31				36
Puerto Rico Region								
National Total	98036	44645	6754	688	435		123	20119

APPENDIX L

SUMMARY OF COST ESTIMATES FOR SOLAR POND POWER PLANTS (EXTRACTED FROM THE SALTON SEA FEASIBILITY STUDY REPORT PREPARED BY ORMAT TURBINES, LTD., 1981)

Table L-1. Salton Naval Base Site 5-MW Experimental Solar Pond Power Plant
Summary of Cost Estimates[a]
(October 1980 price level in US $)

ITEM	Cost (1,000 $) 1st Demonstration SPPP	Cost (1,000 $) 2nd Adjacent SPPP
Solar Pond Subsystem		
Geotechnical Survey	220	120
Solar Pond Construction	6,765[b] - 7,500[c]	6,765 - 7,500
Construction of Evaporation Ponds	2,206[b] - 5,206[c]	-
Brine Ciruclation System	752	600
Cooling System	510	400
Water Flushing System	140	120
Water Treatment Plant	1,000	800
Gradient Control Sytem	650	650
Instrumentation and Controls	72	50
Power Station Yard Development	128	128
Engineering and Design	995 - 1,294	300 - 450
Management, Supervision & Administration	500 - 600	300 - 400
Sub Total	13,938 - 18,072	10,233 - 11,218
Power Generating Subsystem		
Plant Equipment	4,650	4,200
Construction Materials	1,550	1,550
Construction and Installation	800	630
Engineering and Design	700	150
Management, Supervision & Administration	400	150
Sub Total	8,100	6,680
TOTAL	22,038 - 26,172	16,913 - 17,898
Contingencies (15%)	3,306 - 3,926	2,537 - 2,685
GRAND TOTAL	25,344 - 30,098	19,450 - 20,583
O & M Costs - 3 Years	1,541	353

[a]Source: Salton Sea Feasibility Study, Ormat Turbines, Ltd., 1981.
[b]Borrow material within Sea.
[c]Borrow material available on shore.

Table L-2. Bristol Dry Lake Site 5-MW Experimental Solar Pond Power Plant Summary of Cost Estimates[a] (October 1980 price level in US $)

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ITEM	Cost (1,000 $) 1st Demonstration SPPP	2nd Adjacent SPPP
Solar Pond Subsystem		
Geotechnical Survey	96	96
Solar Pond Constr. tion	2,409[b] - 10,082[c]	2,409 - 10,082
Braine Make-up Pond	472	380
Brine Ciruclation System	752	600
Pond Surface Flushing & Cooling System	1,420	1,140
Water Make up System	365	290
Water Treatment Plant	750	600
Provision for Brine & Water Production & Aquisition	1,000	500
Gradient Control Sytem	650	650
Instrumentation and Controls	72	50
Power Station Yard Development	47	47
Engineering and Design	643[b] - 800[c]	250 - 350
Management, Supervision & Administration	400[b] - 800[c]	300 - 700
Sub Total	9,076 - 17,878	7,312 - 15,485
Power Generating Subsystem		
Plant Equipment	4,650	4,200
Construction Materials	1,550	1,550
Construction and Installation	800	630
Engineering and Design	700	150
Management, Supervision & Administration	400	150
Sub Total	8,100	6,680
TOTAL	17,176 - 25,978	13,992 - 22,765
Contingencies (15%)	2,576 - 3,897	2,099 - 3,325
GRAND TOTAL	19,752 - 29,875	16,091 - 25,490
O & M Costs - 3 Years	1,376	188

[a]Source: Salton Sea Feasibility Study, Ormat Turbines, Ltd., 1981.
[b]Option #1: Unlined Pond.
[c]Option #2: Lined Pond.

Table L-3. Preliminary Cost Estimate for 600-MW Solar Pond Power Plant at Salton Sea[a]

Item	Cost (1,000,000 $) (October 1980 Price Level)
Solar Pond Subsystem	
Geotechnical Survey	1
Dredging	100
Dike Construction (including solar ponds, evaporation ponds and brine make-up ponds)	199.4[b]
Brine Circulation System	28.8
Pond Surface Flushing and Cooling	68.4
Water Treatment Plant	36
Gradient Control System	70.2
Instrumental and Control	1.2
Power Station Yard Development	2.4
Engineering and Design	30.4
Management, Supervision and Administration	20.2
Sub Total	558
Power Generating Subsystem	
Plant Equipment	311
Construction Material	145
Construction and Installation	60
Engineering and Design	17
Management, Supervision and Administration	7
Sub Total	540
TOTAL	$1,098

[a]Source: Salton Sea Feasibility Study, Ormat Turbines, Ltd., 1981.
[b]Includes the cost of impoundment dike construction for this 50 square mile region, $108.4 million.